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SAAC EVALUATION OF THE SAAC/LASA SYSTEM

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13. ABSTRACT

This report is an evaluation of the SAAC/LASA system known as the Integrated Seismic Research Signal Processing System which was programmed by IBM.

The system operates in two parts. The Detection Processor performs data acquisition and signal detection. The Event Processor is designed to recognize true signals and false alarms and to extract event parameters, refine locations, and publish an earthquake bulletin. The Event Processor is programmed to work either in an automated mode in which the computer analyzes events and publishes the bulletin without help from a seismic analyst, or to act as an aide to the analyst who can eidt the event processing on a display console.

The Detection Processor works well as a data acquisition, recording, and signal detection system. System parameters such as filters, beam composition and deployment, detection thresholds, and detection logic are adjustable over satisfactory limits. Marginal improvements are possible in the detection processing. Improvement in system raliability beyond its present 90 to 95% will depend first upon improvement in the reliability of the 50 kilobit phone line between LASA and SAAC.

The Event Processor with analyst editing is able to handle the data output from LASA and produce an acceptable seismic bulletin within 24 hours. The LASA Daily Summary lists an average of 30 events per day excluding local earthquakes at a signal-to-noise ratio of five, mostly at distances of 30° to 100° from LASA. The system can be improved in its handling of local events and very large events.

The Event Processor cannot work reliably in the automated mode. As compared to analyst measurements, its false signal rate and missed signal rates are too high; its refinement of location offers little or no improvement over detection beam location; and its estimates of event parameters, especially arrival time and depth estimates, are unreliable. Consequently the outputs from automated LASA/SAAC cannot be used for accurate locations and depths by a precision seismic network.

14. KEY WORDS

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LIST OF ACRONYMS

ALPA	Alaskan Long-Period Array
CPU	Central Processing Unit
DP	Detection Processor
EOC	Experimental Operations Console
EP	Event Processor
EST	Eastern Standard Time
GMT	Greenwich Mean Time
IISPS	Interim Integrated Signal Processing System
ISRSPS	Integrated Seismic Research Signal Processing System
LASA	Large Aperture Seismic Array
LDC	LASA Data Center
LP	Long-Period
LTA	Long Time Average
MSTA	Maximum Short Time Average
NDPC	Norway Data Processing Center
NORSAR	Norwegian Seismic Array
NOS	National Ocean Survey
SAAC	Seismic Array Analysis Center
SAB	Subarray Beam
SAQ	Signal Arrival Queue
SDL	Seismic Data Laboratory
S/N	Signal-to-Noise Ratio
SPS	Special Processing System
STA	Short Time Average
3/3	3 out of 3 Detection Logic
4/4	4 out of 4 Detection Logic

I. INTRODUCTION

The main objective of the large seismic arrays has been to improve the signal-to-noise ratio and weak signal detection for teleseismic earthquakes and explosions. Since the many seismometers of a large array require a digital computer for the data acquisition and recording, it is advantageous to utilize the computer to automate the detection analysis processes as well.

The purpose of this report is to evaluate the existing SAAC automated data acquisition and processing systems developed by the Federal Systems Division of IBM under contract F19628-67-C-0198 and F19628-68-C-0400. Teledyne Geotech has operated SAAC utilizing the IBM data acquisition and processing systems on a 24-hour day, 7-day week basis since January 15, 1971. We have published a LASA Daily Summary (earthquake bulletin) since February 1, 1971.

This report is primarily a geophysical evaluation of the short period SAAC/LASA system as it operated from February 1 to May 16, 1971. The report covers only the latest version of the IBM detection processing and event analysis programs*. The report does not evaluate

*The Integrated Seismic Research Signal Processing System known as ISRSPS.

older, interim systems of IBM programs**, nor the data acquisition system in Montana.

In subsequent evaluation reports we will evaluate the long period (LP) arrays, LP data, and LP analysis systems from the three arrays in Montana, Alaska, or Norway. Another report will also give a more complete evaluation of the system hardware configurations and software systems.

**Interim Integrated Signal Processing System known as IISPS.

II. THE SAAC - LARGE ARRAY SYSTEM

Data recording and transmission

Currently, there are three large seismic arrays in operation feeding data to SAAC. Figure 1 shows the geographic arrangement. The first of these, the Large Aperture Seismic Array (LASA) in Montana is composed of 21 subarrays in a log-periodic distribution over an area with a 200 km diameter. Each subarray contains 16 short-period vertical seismometers distributed over a circular area with a 7 km diameter (the E-3 subarray has 25 sensors over an area with a 20 km diameter) and one three component long-period system. The short period data are digitized at 20 samples/sec and the long-period data at 5 samples/sec. All the data are multiplexed and decimated to 10 samples/sec and 1 sample/sec, short- and long-period respectively, and transmitted via a 50 kilobit line to SAAC in Alexandria, Virginia.

The recently completed Norwegian Seismic Array (NORSAR) is composed of 22 subarrays in a circular distribution over a 100 km diameter area. Each of the subarrays contains six short-period vertical seismometers within a 10 km diameter area and a three component long-period system. The digitizing rates for the short- and long-period data are 20 samples/sec and 1 sample/sec respectively. All of the data are processed at NORSAR; selected short-period data channels and all long-period data channels are transmitted to SAAC via a 2.4 kilobit Trans-Atlantic Link.

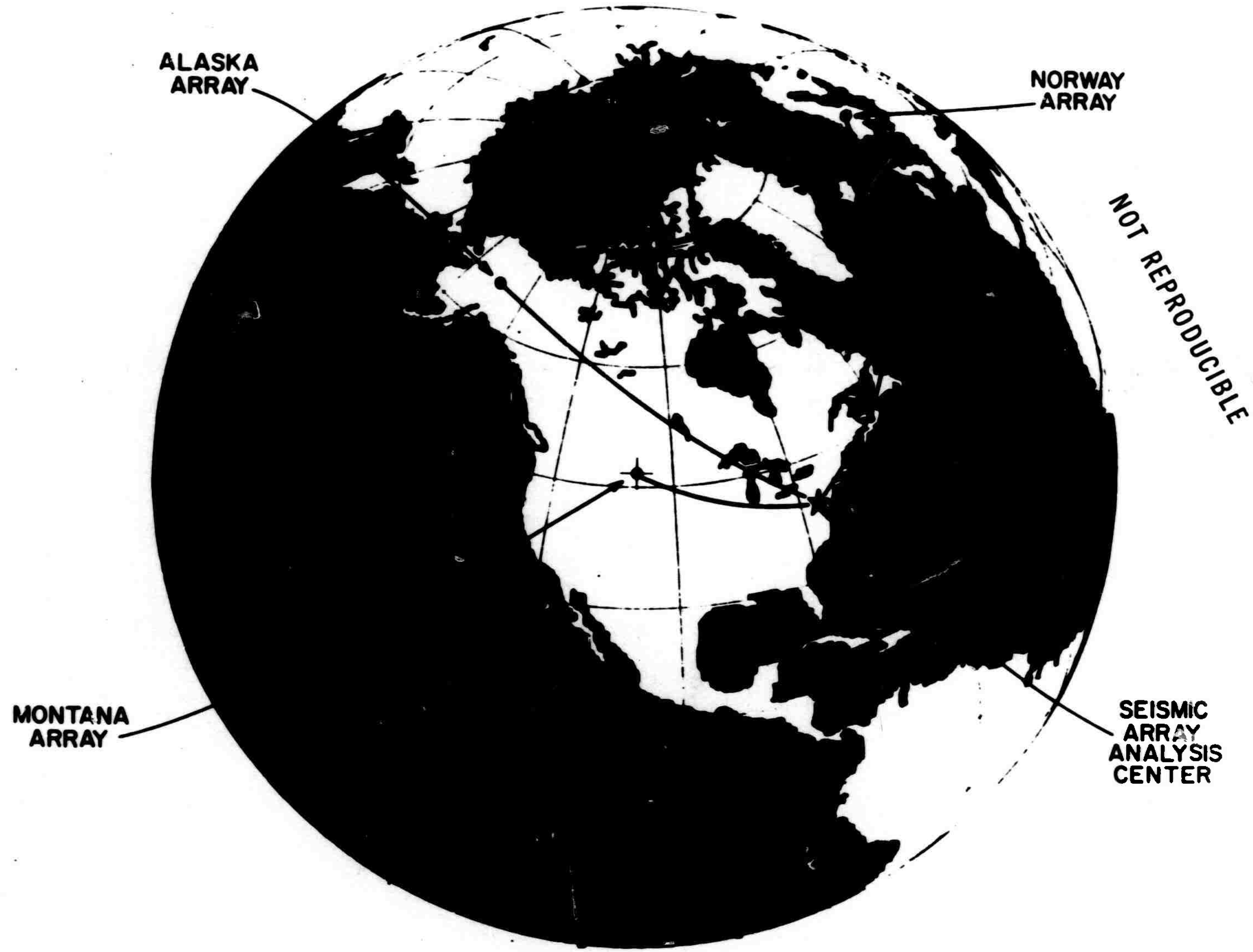

Figure 1. Geographic distribtuion of the Larage Array Network.

The third large array, the Alaskan Long-Period Array (ALPA) is composed of 19 sites hexagonally distributed over an area with an 80 km diameter. Each site has three (triaxial) long-period seismometers, with gain-ranged amplifiers. Data are sampled at 1 sample/sec, multiplexed, and transmitted to SAAC via a 2.4 kilobit line. The layouts of all three arrays and related information are shown in the Appendices.

SAAC processing system

SAAC processing operations are divided into two major parts, the Detection Processor (DP) and the Event Processor (EP). As shown on Figure 2, the functions of the DP are to receive and record data from the large arrays and to detect signals in the LASA short-period data. DP operates on-line in real-time.

The functions of EP are to analyze the signals detected by DP, to eliminate the false alarms, to compute event parameters such as size and location, and to publish an earthquake bulletin (LASA Daily Summary). EP operates off-line. The block diagram in Figure 3 indicates the present equipment configuration designed to accomplish these purposes.

All data transmitted to SAAC first enter the Special Processing System (SPS). The functions of the SPS are to demultiplex all data, to form LASA short-period subarray beams (five per subarray), to form LASA long-period array beams, ALPA array beams, and to filter (0.9 to 1.4 Hz) all of the short-period subarray beams.

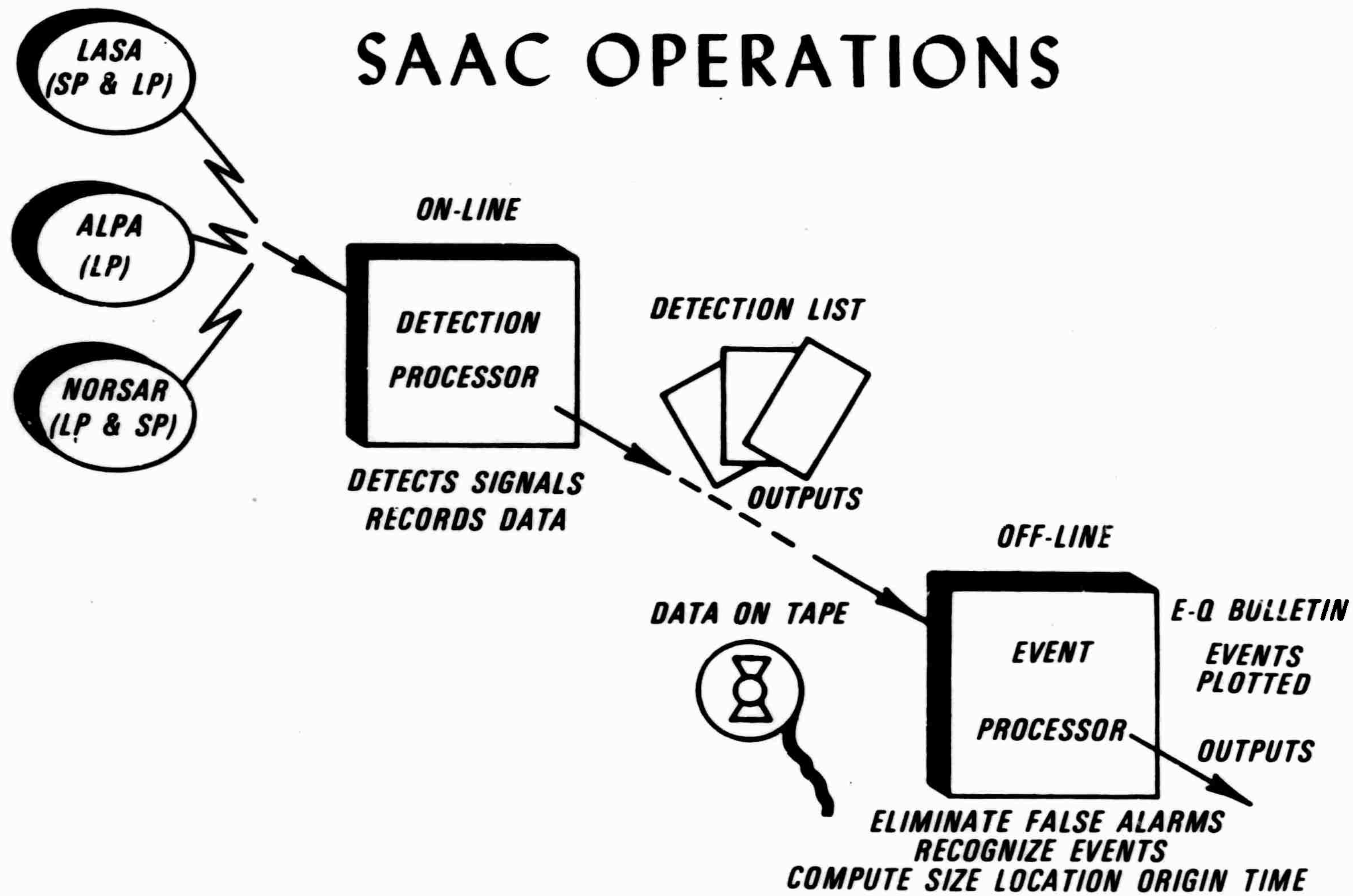

Figure 2. SAAC operations.

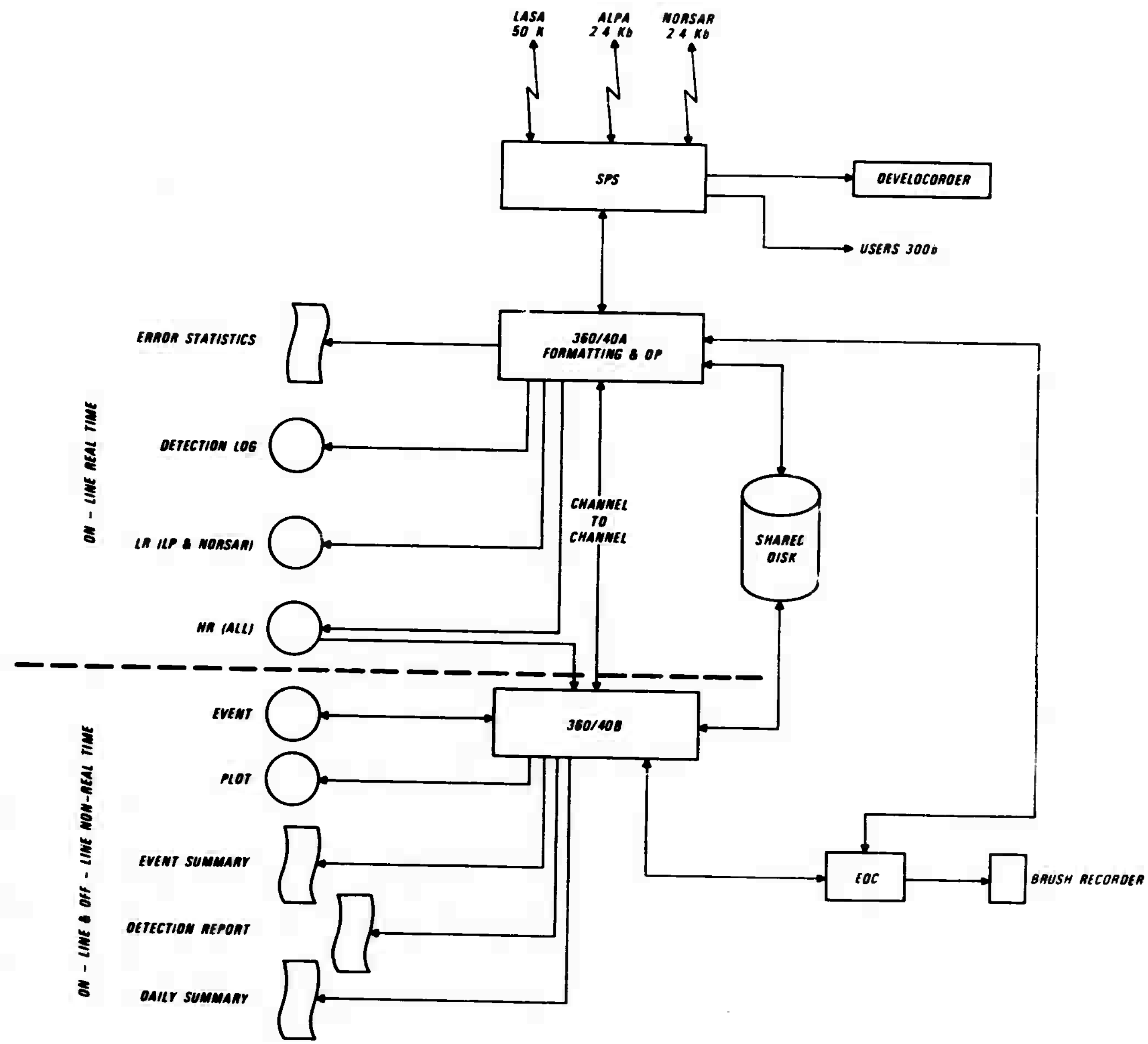

Figure 3. SAAC system configuration.

The outputs of the SPS, including all raw data and filtered subarray beams, are transmitted to the IBM 360/40A computer. In addition, selected ALPA data traces are recorded on a Develocorder, and all ALPA data are transmitted to outside users via a 0.3 kilobit line.

The functions performed within the IBM 360/40A computer include data recording and signal detection. All data from the three arrays are recorded onto a 9 track, 1600 BPI high-rate data tape. A low-rate tape is also generated which includes all long-period data from the three arrays as well as the selected short-period NORSAR data. Systems status monitoring and communications via the SPS with LASA Data Center (LDC) at Billings and with the Norway Data Processing Center (NDPC) at Oslo, are other systems functions.

The principal seismic function performed in the IBM 360/40A is the detection processing of LASA data. Basically, the DP logic first forms 300 selected array beams using the filtered beams from 17 subarrays (A-ring through the E-ring) and 299 array beams using the filtered beams from nine subarrays (A-ring through the C-ring). Long Time Averages (LTA's), computed from rectified data over a preset time window (28.8 seconds), are used as a measure of the noise level, and are continually updated for all 599 beams. Short Time Averages (STA's) of preset length (1.8 seconds), representing signal plus noise level, are also computed from rectified data and continually updated. Then ratios of STA/LTA which approximate the signal-to-noise ratio are formed. Before a detection can be

declared, the value of STA/LTA must exceed the input threshold parameter q consecutive times out of p. Parameters (p and q) currently used are that the ratios must be greater than 10 db, 7 db, and 7 db for three consecutive ratio calculations out of three (referred to as 3 out of 3); or 10 db, 7 db, 7 db and 7 db for four consecutive ratios out of four (referred to as 4 out of 4). After a detection has been determined, retrieval parameters are written on a detection log tape for storage and onto a disk unit that is shared with the IBM 360/40B computer. The entries on the disk comprise the Signal Arrival Queue (SAQ) which contains the time interval over which each detection was determined, the beam number and corresponding location, and the values of STA and LTA measured on the detecting beam.

The principal function performed in the IBM 360/40B is the Event Processing. The EP first reads the SAQ and writes a list of the detections on a printer. It also performs a multistepped selection process on the SAQ whereby it screens the detections to determine which detections are to be processed as events. The EP screening includes a threshold test (equal to or greater than the DP threshold), time and location comparisons to determine if the detection is a side lobe of another detection or a closely arriving later phase, a check to see if the detection is duplicated on both partitions of beams, and a system of priorities designed to allow the system to keep functioning when it may be overloaded by aftershock activity from a major earthquake.

Once a detection has been selected for processing, the EP acquires the raw data from the previously recorded high-rate tape, forms subarray beams and a full array beam aimed at the location of the detecting beam, and filters (0.8 to 2.5 Hz) the newly formed time series. The system then attempts to improve the detection location by cross-correlating each of the subarray beams with the array beam. Using the set of time delays from the cross correlation procedure, a plane wave solution is obtained from which apparent velocity and azimuth are calculated. If, however, cross correlation fails, an alternate technique is employed which packs a set of array beams around the detection location and accepts the one with the greatest power as the location.

Regardless of the method, the resultant location is corrected for bias and the event parameters are extracted. The parameters include the signal arrival time, the dominant period, and the maximum amplitude. Whenever possible a depth of focus is estimated for the event based on later arriving energy, with a depth of 33 km assigned if a depth phase is not detected. Finally a body-wave magnitude is computed using the above parameters and the distance to the epicenter.

After the event has been processed, it is available for review on the Experimental Operations Console (EOC), where an analyst can substantiate and modify the subarray beam alignment and the parameters determined by the EP. The edited event is then written on an Event Tape where it is stored

for future reference; the data set for each event (subarray beams and array beam) is plotted, and the parameters are output in punched card form. A daily bulletin is transmitted via teletype to external users and to the Seismic Data Laboratory (SDL) where the epicenters are combined into a weekly summary.

III. DETECTION PROCESSING

The DP system

The basic functions of the entire DP were described in Section II. This section describes in more detail the seismic functions performed in DP for beamforming, filtering, and signal detection.

The following sequence of operations is performed within the SPS and 360/40A:

1. Subarray beamforming
2. Filtering
3. Array beamforming
4. Short Time Averaging
5. Long Time Averaging
6. Thresholding

Subarray beamforming. - A subarray beam is formed by time-shifting and summing the data from 16 seismometers in a subarray. The time shifts are those for a plane wave assuming an apparent velocity and azimuth. Five different beams are computed for each of 17 subarrays (the F-ring is omitted). These five subarray beams are uniformly dispersed in azimuth, with center velocities of 15.45 km/sec but responding to signals with velocities ranging from 8.9 km/sec to 56.5 km/sec. The subarray beams (non-averaged) are computed in the SPS as

$$SAB_{jk}(t) = \sum_{t=1}^{16} x_{ik}(t + \tau_{ijk})$$

where

i = seismometer (total of 16)
j = beam (total of 5)
k = subarray (total of 17)
τ_{ijk} = time shift for ith seismometer, jth beam, kth subarray.

Filtering. - Filtering of each of the subarray beams (a total of 17 x 5 = 85) is performed in the SPS using a three-pole recursive Butterworth filter in the pass-band of 0.9 to 1.4 Hz. The filtered subarray beam is computed as

$$g_{kj}(t) = \sum_{p=o}^{P-1} a_{pkj} SAB_{jk}(t - p\Delta t) + \sum_{p=1}^{P-1} b_{pkj} g_{kj}(t - p\Delta t)$$

where a and b are appropriate filter coefficients and Δt is the sampling rate of 10 samples/sec. The filtered outputs are averaged to a single instrument value as

$$g_{kj}(t) = \frac{1}{16} g_{kj}(t)$$

and transmitted to the 360/40A for futher processing.

Array beamforming. - The array beamforming operation is a delay-and-sum of the filtered SAB's. Two types of array beams, referred to as Partition I and

Partition II, are formed by using, respectively, 17 subarray beams (A0 through the E-ring) and 9 subarray beams (A0 through the C-ring). A total of 300 beams are formed for Partition I and 299 for Partition II. The beam deployments for both partitions are given in Appendix II. The non-averaged array beam is computed as

$$B_j(t) = \sum_{k=1}^{K} g'_{kj}(t - \tau_{kj})$$

where

k = subarray

K = number of subarrays; 17 for Partition I, 9 for Partition II

j = beam

τ_{kj} = time shift for kth subarray, jth beam.

The array and partial-array beam operations are performed at a 5 Hz rate, the decimation yielding a Nyquist frequency of 2.5 Hz.

<u>Short time averaging</u>. - The STA is obtained in a two-step process. The first step computes a scaled rectified sum over three consecutive digital points of each beam output to obtain an STA update:

$$y_j(t) = \frac{1}{32} \sum_{S=0}^{2} |B_j(t - S\Delta t)|$$

where the factor 1/32 provides a scaling capability to minimize overflows in the subsequent processes. The second step computes the final STA by using the STA update:

$$STA_j(t) = STA(t - 3\Delta t) + y_j(t) - y_j(t - 9\Delta t)$$

where $STA(t - 3\Delta t)$ = previous STA

$Y_j(t - 3\Delta t)$ = oldest (0.6 sec earlier).

<u>Long time averaging</u>. - The LTA is computed for each beam as an exponentially-weighted sum of the STA with an equivalent length of 16 STA values (28.8 sec).

$$LTA_j(t) = \tfrac{1}{2}STA_j(t) - \tfrac{1}{32}LTA_j(t - \Delta t) + LTA_j(t - \Delta t)$$

$$= \tfrac{1}{2}STA_j(t) + \tfrac{31}{32}LTA_j(t - \Delta t)$$

Letting k = 31/32,

$$LTA_j(t) = \frac{1}{2} \sum_{p=0}^{\infty} k^p STA_j(t - p\Delta t)$$

where $\frac{1}{2} \sum_{p=0}^{\infty} k^p = 16$. This shows that the LTA exponential weighting has an equivalent scale factor of 16 and that the LTA is 16 times the STA.

Thresholding. - The thresholding operation performs the function of determining an actual detection by testing if the S/N exceeds a preset threshold. Two thresholds are computed:

$$T'_j(t) = \frac{1}{1024}[202LTA(t)], \quad \text{Start Threshold}$$

and $$T_j(t) = \frac{1}{1024}[143LTA(t)], \quad \text{End Threshold}$$

Because the LTA is 16 times the STA, the average noise amplitude relative to the STA is

$$N_j(t) = \frac{1}{16}LTA(t)$$

and the thresholds, in decibels, are

$$T'_j(t) = 20 \ Log_{10}\left[\frac{T'_j(t)}{N_j(t)}\right] = 20 \ Log_{10}\left[\frac{2^{-10} \ X \ 202 \ X \ LTA(t)}{2^{-4}LTA(t)}\right]$$

$$= 20 \ LOG_{10}(202/64) = 10 \text{ db}$$

and $T_j(t)$ = 7 db. When a current STA exceeds the Start Threshold and the subsequent two or three STA's exceed the End Threshold as well, a detection is declared. If two subsequent thresholds are used, the detection process is referred to as 3 out of 3; if three subsequent thresholds are used, it is 4 out of 4.

Detection rates and noise levels

A detection is defined as any crossing of the DP threshold in the ratio of STA/LTA. If a group of beams on either partition I or II, all exceed the threshold, the maximum STA (MSTA) of the group is selected; however, if both partitions have a beam or a group of beams exceeding the threshold, the detection is counted twice.

During the period from February 1 to May 16, 1971, the DP operated at a threshold of 10 db under both 3 out of 3,(3/3) and 4 out of 4,(4/4) logic. The daily detection rate is shown in Figure 4. The dates when a change in logic occurred are indicated. For the month of February with 3/3, the average daily detection rate was 1129 with a standard deviation of 160. For days with less than a full 24-hour recording period, the daily rate was scaled to 24 hours (by the ratio of 24 hours/number of hours recorded). The fewest number of recording hours for any day in February is 14. Approximately 15% of the February detections are duplicates, having been reported on both partitions.

After February, the DP operated under 4/4, and

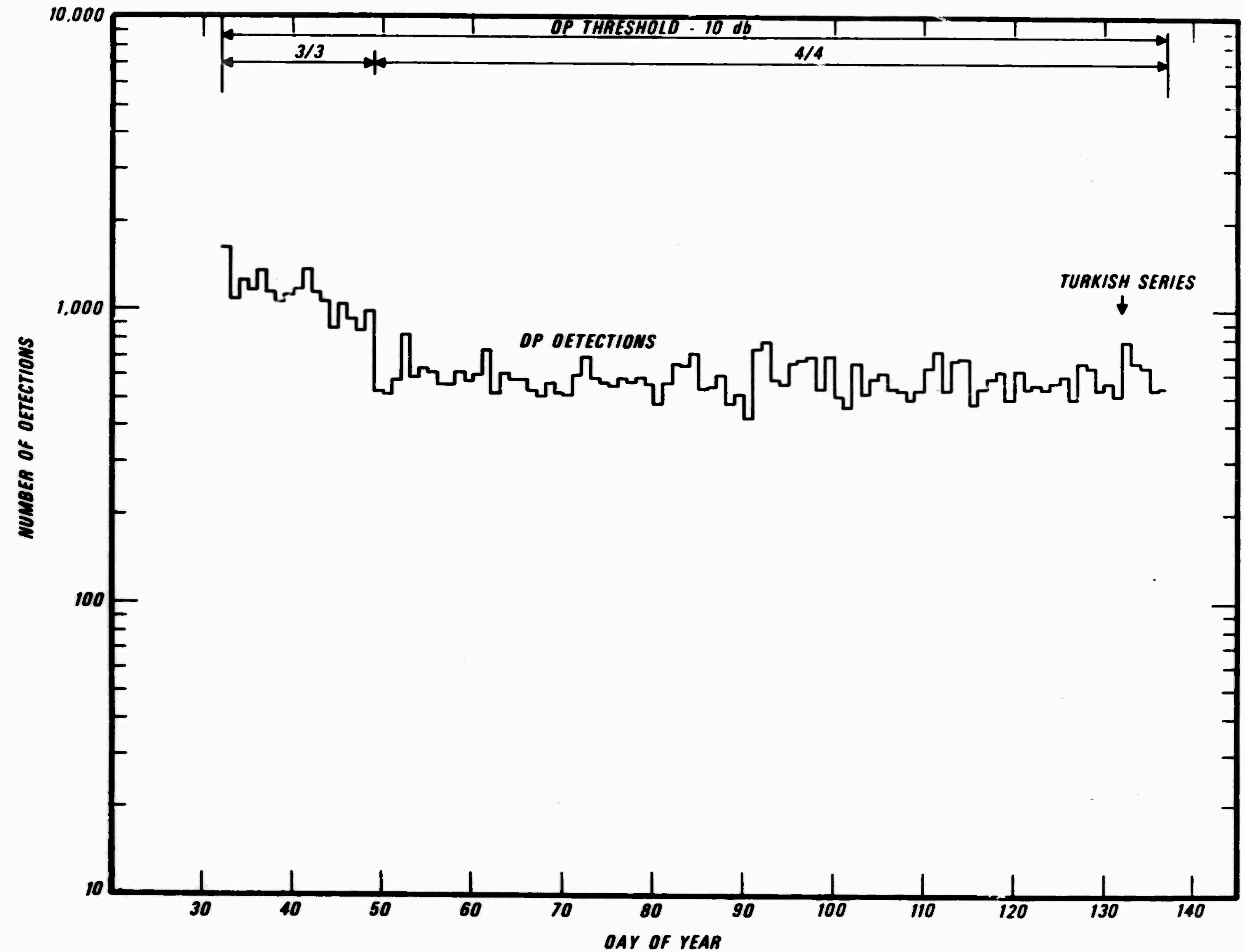

Figure 4. Daily detection rates.

the average number of daily detections decreased to 558 with a standard deviation of 59. About 20% of these detections are partition duplicates.

On Day 132 (May 12, 1971), the increase in the daily rate was due to aftershock activity of a large event in Turkey ($m_b \cong 6$).

Figures 5 and 6 show plots of cumulative percentage number of detections as functions of signal-to-noise ratio (STA/LTA) for 3/3 and 4/4 respectively. Both curves show that small changes in detection-threshold settings can produce large changes in the numbers of detections per day. For example, when operating with 3/3 at 10 db (S/N - 3.16), the number of detections drops to 51% at 12 db (S/N = 4) and to 26% at 14 db (S/N = 5). For 4/4, a 12 db setting would produce a drop to 54% and 14 db to about 30%. Note, that for both 3/3 and 4/4, the rates of increase in number of detections decrease slightly as the S/N approaches the threshold of 10 db. This effect is observed because the detection algorithm requires both size (greater than 10 db in the first time interval) and duration (greater than 7 db for the next two or three intervals). Therefore, regardless of which level the threshold is set, the number of detections would be expected to decrease as that threshold is approached.

Figures 5 and 6 also show that a significant number of detections are listed in the Detection Report which are below the 10 db threshold. For both sets of logic, about 5% of the total number of detections are

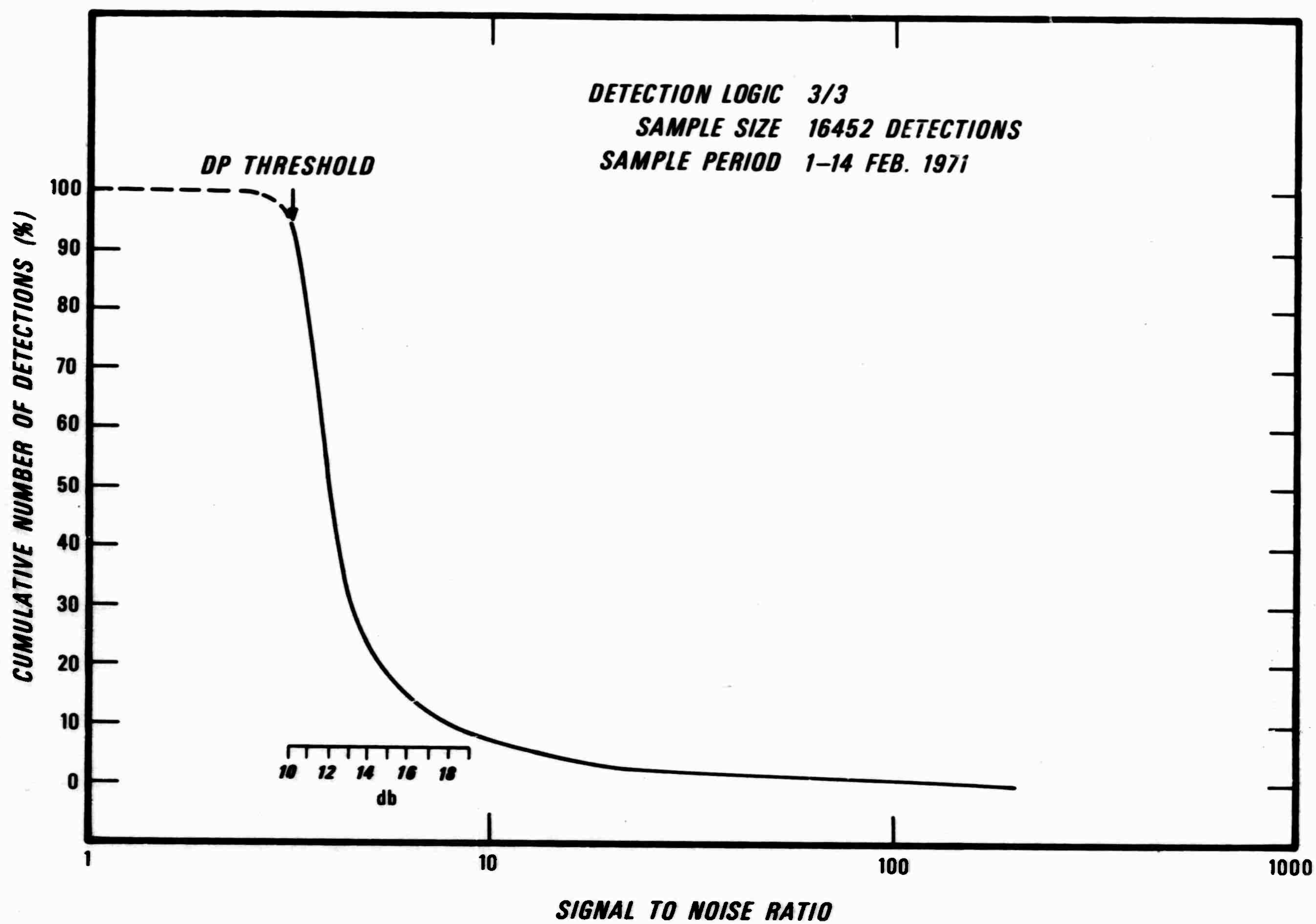

Figure 5. Percentage of detections vs signal-to-noise ratio for 3/3 logic.

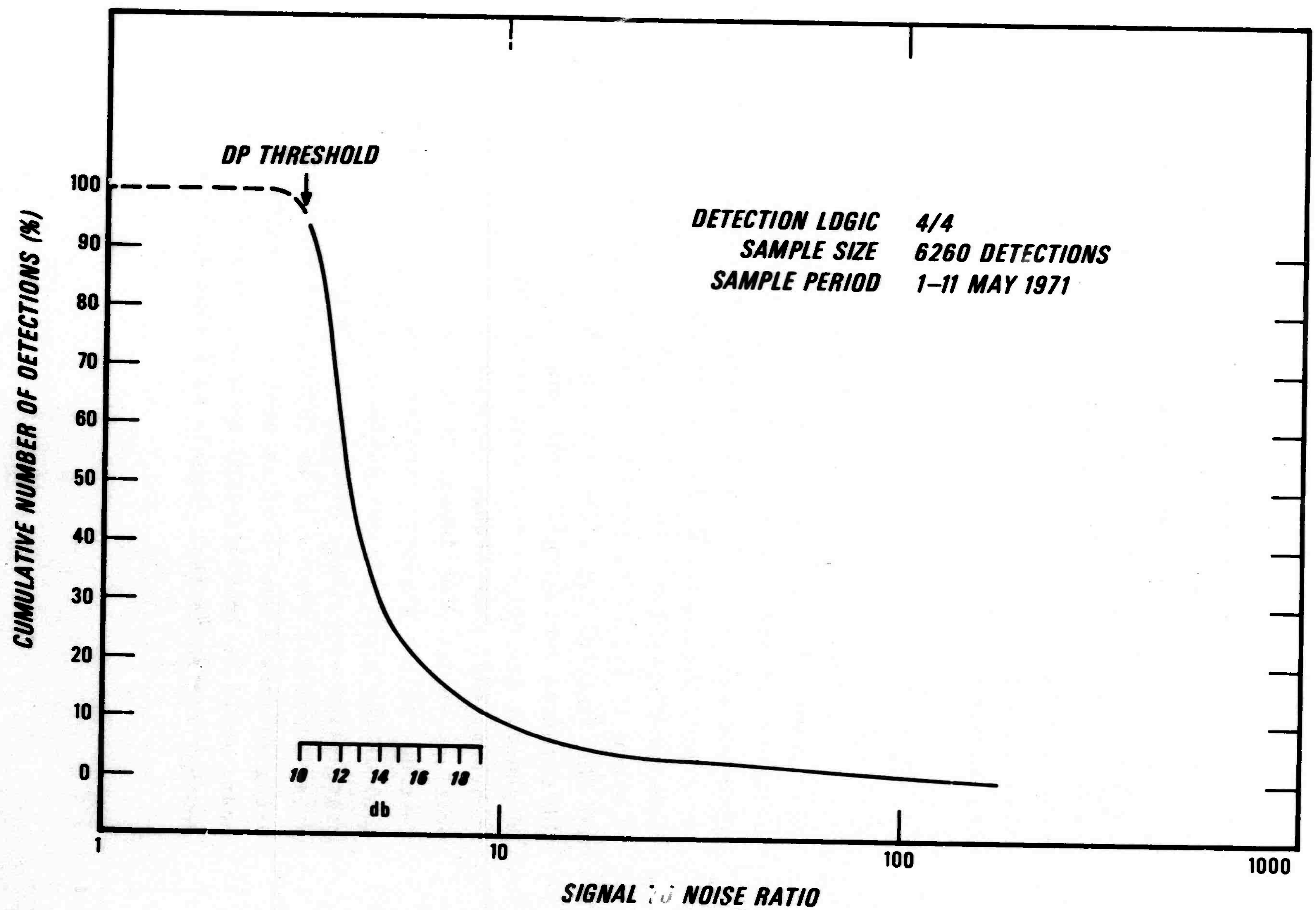

Figure 6. Percentage of detections vs signal-to-noise ratio for 4/4 logic.

allowed to pass through the system at a S/N less than 3.16. The reasons for this are not entirely clear at this time. A possible explanation is that if the LTA was updated during a detection (signal being mixed with noise), the detection would still be valid but the output S/N would be less than that obtained with the non-updated LTA. Another possibility is that periodic data dropouts may contribute to the effect.

Duplicate detections. - Duplicate detections from Partitions I and II are compared on Figure 7. Recall that Partition I beams are formed with 17 subarrays (fine beams) and Partition II with 9 (coarse beams). Therefore, if the fine beams point exactly at the epicenter and if no signal decorrelation occurs across the array, the expected S/N gain of fine over coarse beams is proportional to $(17/9)^{1/2} = 1.37$ (about 2.8 db). As shown in Figure 7, the gain is about 1.13 (1.1 db) not the expected 1.37. There are several reasons why the observed average gain falls short. The fine beams in general are not pointed exactly at the position of an event; and, even though the fine-beam deployment overlaps at the 3 db level, as much as 1 db may be lost due to the misfocus. Another reason may be that some of the beams are not suitably corrected for travel-time anomalies. Since coarse beams are formed using subarrays over a 13 km radius, and fine beams using subarrays over a 50 km radius, the coarse beams would be less affected by miscalibration. Still another reason is that signals will tend to be more

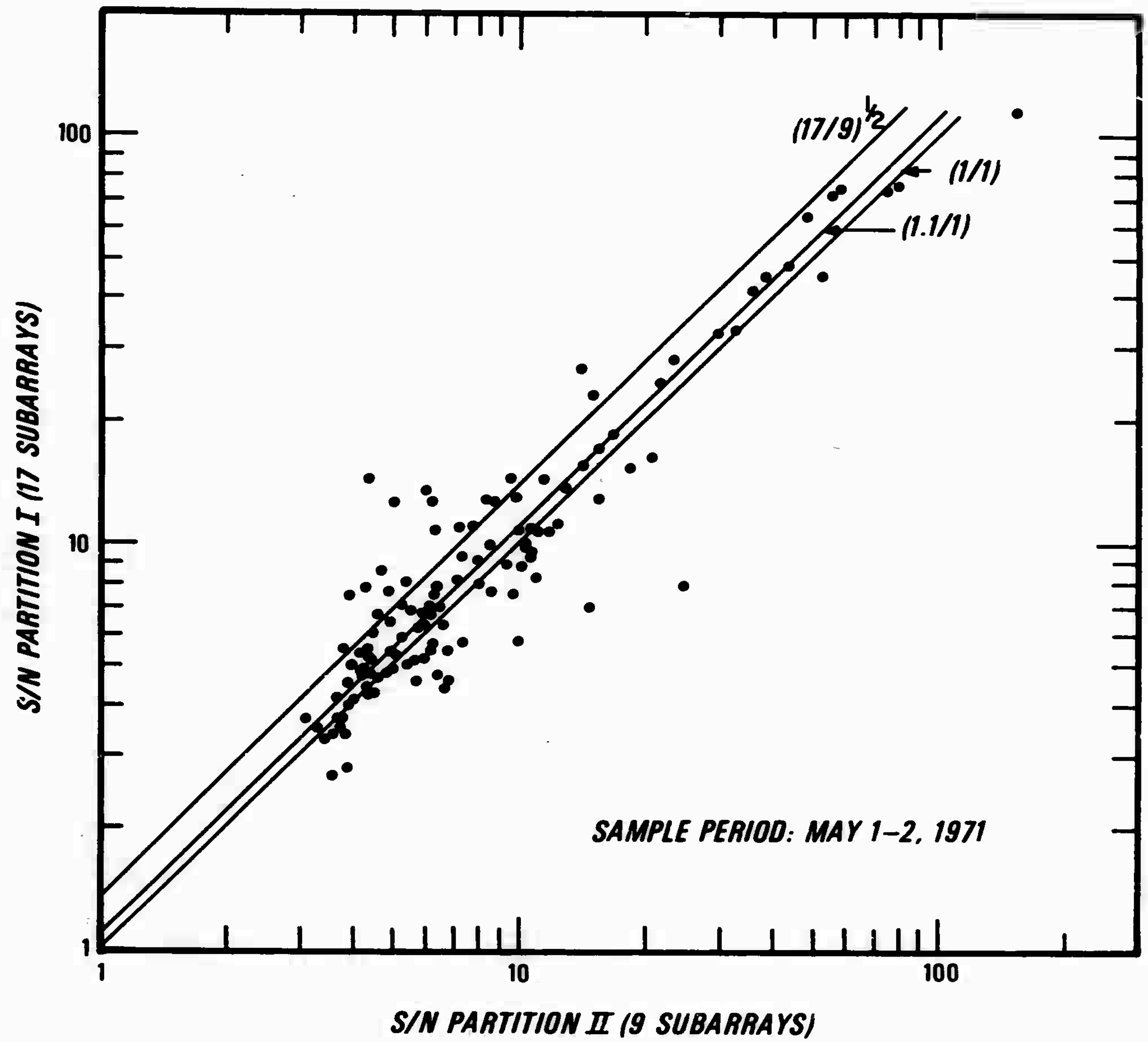

Figure 7. Signal-to-noise ratio comparisons of duplicate detections.

decorrelated over 100 km as in the fine beams than over 25 km as in the coarse beams. The expected 2.8 db gain assumes no signal decorrelation.

Hourly detection rates. - The average hourly detection rates for two-week periods in February, March, April, and a 12-day period in May, are shown in Figure 8.

In February the DP operated under 3/3 logic and the numbers of detections are higher than subsequent months under 4/4. All of the curves show reduced hourly detection rates between about 1100 and 0100 GMT (0500 and 1900 LASA local time). During February, a pronounced increase in the middle of this time period is indicated; the other months also show an increase but not as pronounced. From February to May, an increase is observed in the length of time the reduced detection rate persists; this suggests a correlation with daylight hours at LASA when ambient noise tends to increase.

LASA background noise levels. - During the period May 1-10, 1971, we measured the noise levels on those detection beams listed by the DP. The criterion for accepting a listed LTA was that the preceding detection must have been at least five minutes prior to the LTA so as to minimize signal contamination.

Figure 9 shows the average hourly noise levels, in millimicrons, for both Partition I (17 subarrays) and Partition II (9 subarrays). There are several facts to note on this figure. The noise levels for

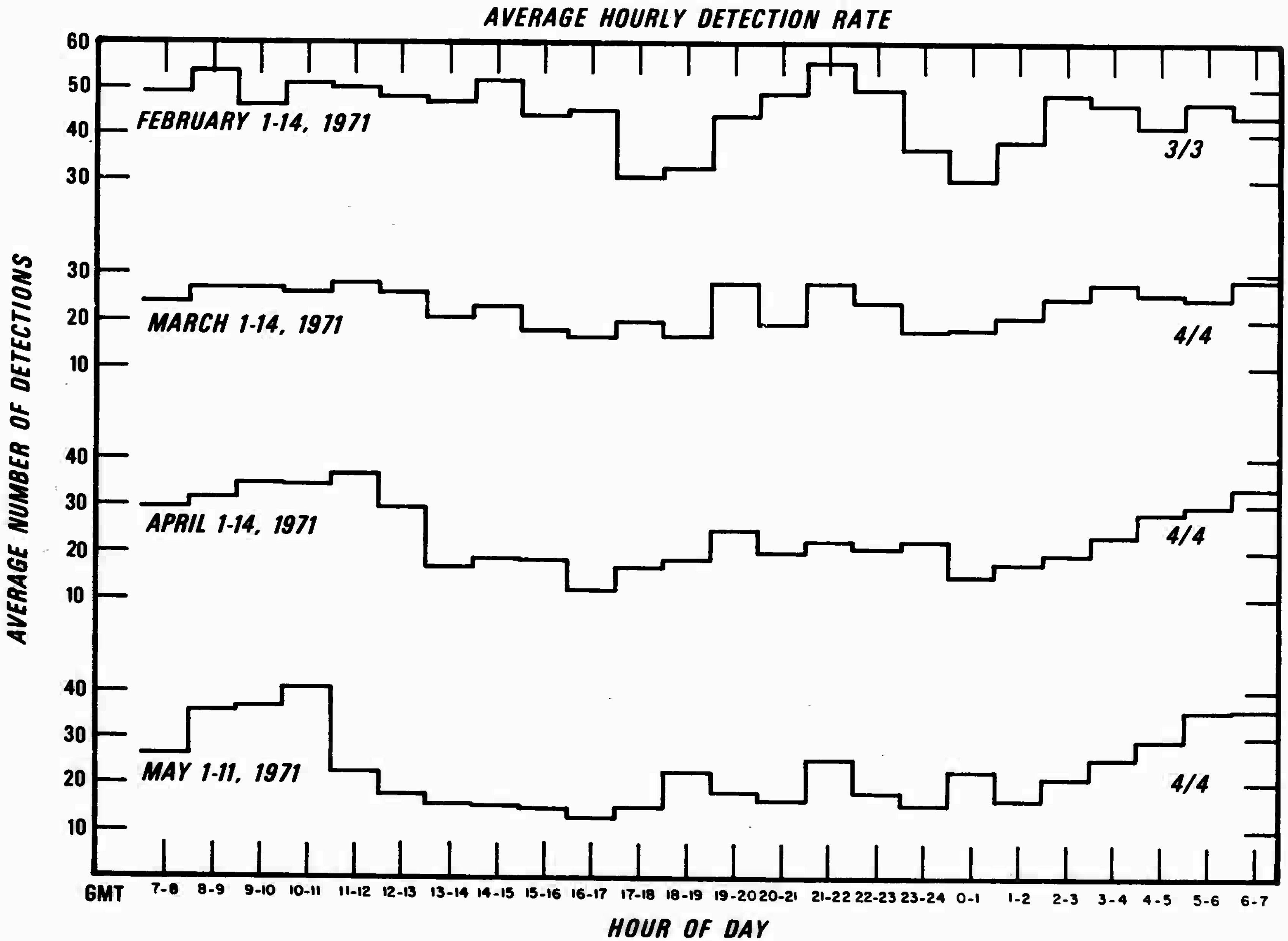

Figure 8. Average hourly detection rate.

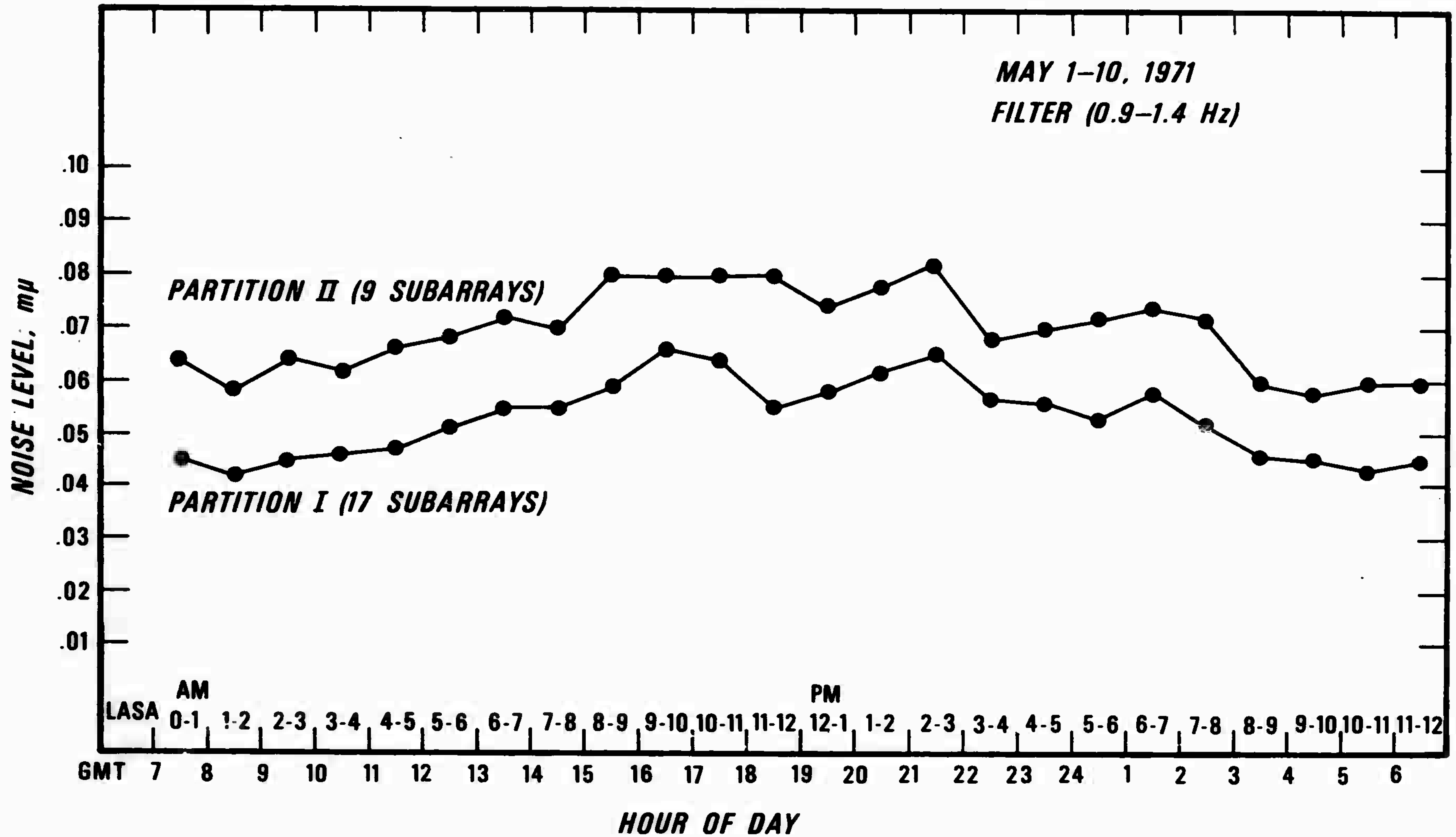

Figure 9. Average hourly noise levels for Partitions I and II.

both Partitions generally increase during daylight hours at LASA, especially for Partition I where the increase is by 50%. The noise levels should be viewed with the hourly detection rates shown on Figure 8, which shows the detection rate varying inversely with the change in the noise level. If the majority of detections reported by the DP were actually false alarms caused by a Gaussian process, the detection rate would not vary as a function of noise but would remain approximately constant. Thus the results suggest that the majority of detections occurring between the DP threshold of 10 db and the EP threshold of 14 db may be valid signals. This possibility is being investigated.

The noise levels shown for Partition II on Figure 9 have been multiplied by 2 in order to account for a scale factor error as the system was turned over to us.

<u>DP system reliability and utilization</u>

We started recording on the DP routinely at 2300 GMT on January 15, 1971 following the move and check out of the equipment from the Van Ness Center. Table I shows the DP uptime and downtime for January 15 through May 31, 1971. This table does not reflect recording time of the interim system (DP-IISPS) nor the recording at the LASA Data Center in Montana used for backup since we have made no effort during this period to analyze backup data and report those events in the LASA Daily Summary.

TABLE I

SAAC - DP Up-Downtime in Hours

for January 15, 1971 through May 31, 1971

Month	Jan	Feb	Mar	Apr	May	Total
Problems						
Training	96.0	-	-	-	-	96.0
SAAC Comptr. Room	-	31.4	13.7	11.8	1.2	58.1
SPS	12.4	3.5	41.3	16.9	0.0	74.1
50 KB Phone Line	56.8	12.7	14.0	3.7	50.2	137.4
Prev. Maint.	5.4	6.6	8.0	9.0	6.3	35.3
Total DP Downtime	170.6	54.2	77.0	41.4	57.7	400.9
Total DP Uptime	214.4	617.8	667.0	678.6	686.3	2864.1
Total Possible Recording Time	385.0	672.0	744.0	720.0	744.0	3265.0
% Uptime	56%	92%	90%	94%	92%	88%

All problem categories causing downtime reflect hardware failures except the 96 hours in January for training which includes familiarization difficulties and the lack of operational and software manuals. The category for the SAAC Computer Room includes the IBM 360/40's and their peripherals. Although individual units had collectively more downtime than shown on the table, the DP system was not down as much since the Central Processing Unit's (CPU's) tape units and disk drives are duplicated at SAAC and serve as backups. Figure 10 is a histogram showing the percentage of each day that DP (ISRSPS) recorded LASA short-period data.

The SPS 4103 is the front end of SAAC. It receives data from the telephone MODEM's, checks for polycode (transmission) errors, forms subarray beams, filters, reformats, and supplies data to the IBM 360/40A. It has no backup, so DP-ISRSPS goes down whenever the SPS is down. The difficulties in January seemed to be largely poor connections acquired during the equipment move from the Van Ness Center. The large downtimes in March and April were due to two different equipment failures. Since the SPS is not duplicated at SAAC and since the SPS is not a commercial unit, IBM maintenance engineers spend more time finding failures in the SPS than in a more familiar, commercially available IBM computer.

The 50 KB phone line failures account for more DP downtime than any other cause. This category also includes failures at the LASA Data Center since the effect on SAAC is the same. However, LDC failures

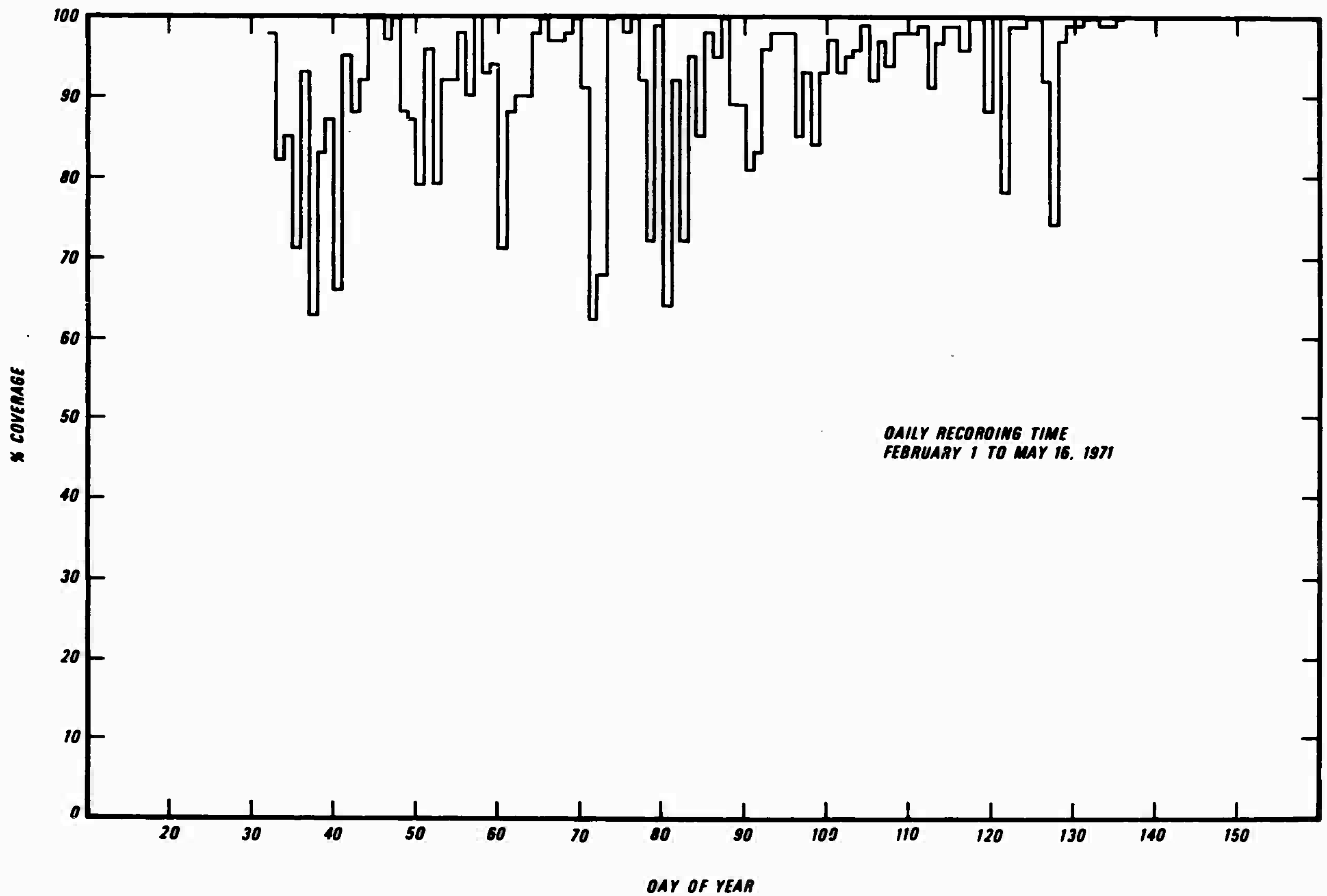

Figure 10. DP (ISRSPS) daily recording time (percent coverage).

account for less than 10 hours of the 137 hours total attributed to the phone line. The 137 hours includes a planned 37 hour shut down by AT&T on May 17th and 18th so that part of the link could be rerouted underground. By this rerouting, AT&T hopes to prevent some of the phone line outages caused by fog in late winter and early spring.

CPU (360/40A) utilization for various DP tasks is shown by Table II. The analysis is for a total of 33 hours in June but is typical of how DP operated from February through May. The CPU attention required by the data acquisition, tape recording, and detection processing tasks is virtually constant. During the wait time, the CPU is available for processing but not occupied. When the EOC time increased, a corresponding decrease took place in the wait time. Most of the 43% wait time of the CPU is available for extra on-line DP processing. Thus, DP tasks can be expanded, provided necessary disk and/or core space is available.

Queuing problems

All real-time systems, such as the ISRSPS Detection Processor, must contain some method of effectively allocating system resources. In this case, the resources which have caused some operational difficulties have been core and random access disk storage. The DP system uses a queuing technique, essentially a waiting line, to control the management of core and disk storage.

The disk storage queue is formally called the Signal

TABLE II

IBM 360/40A Utilization for Various DP Tasks

TASKS		Jun 22	Jun 23	Jun 24	Jun 24	Jun 25
	from	12/40/20.5	19/56/38.0	13/13/36.5	18/46/46.0	21/10/37.0
	to	21/01/37.0	21/18/06.0	18/46/46.0	21/10/37.0	12/34/25.0
DATA ACQUISITION		10.2%	9.9%	10.1%	10.4%	10.5%
TAPE RECORDING		2.5%	2.6%	2.5%	2.6%	2.5%
HIGH PRIORITY MESSAGES		0.0%	0.0%	0.0%	0.0%	0.0%
EOC TEST TIMES		2.6%	2.6%	2.6%	5.2%	6.6%
DETECTION PROCESS		41.1%	40.9%	40.9%	40.9%	40.9%
LOWPRIORITY MESSAGES		0.1%	0.1%	0.1%	0.1%	0.1%
DISK RECORDING		0.0%	0.0%	0.0%	0.0%	0.0%
WAIT		43.3%	43.7%	43.6%	40.6%	39.1%
TOTAL		99.8%	99.8%	99.8%	99.8%	99.7%
	hours	8/21/16.5	1/21/28.0	5/33/09.5	2/23/51.0	15/23/48.0

Arrival Queue. It resides on a shared disk and is written by DP and read by the Event Processing system. As the DP system detects signal arrivals, it stores the arrival information in the Signal Arrival Queue for further analysis by EP. Each entry contains the start and stop time of the detection, the maximum STA, the LTA, and a pointer to the appropriate locating beam information. As the EP system reads the queue and reduces the data, the entries are subsequently freed for additional detections to be stored by DP.

The Signal Arrival Queue has a total of 439 entries. Thus, if 1000 detections are being recorded by DP in a day, as is the case with a 3 out of 3 detection logic and a 10 db detection threshold, the EP system must operate less than 12 hours behind the DP system or take a chance on queue overflow. A Signal Arrival Queue overflow would, of course, mean lost signal detections. More disk space for the SAQ would be desirable at current detection thresholds and necessary if detection thresholds were lowered.

IV. EVENT PROCESSING

The EP system

The Event Processor uses two inputs, the Signal Arrival Queue listing all detections found by DP on the shared disk and the high-rate LASA data tapes recorded previously by DP. The functions of EP are to eliminate the false alarms from the detection list (DP output) and to extract parameters and publish an earthquake bulletin of those detections verified as events.

A great number of signal arrivals detected in the DP system are false alarms, local events, or small events. There are also many signal arrivals detected both on Partition I, the 300 fine beams, and on Partition II, the 299 coarse beams, but listed independently as if they were different events. The EP system reduces the number of detections in the SAQ before signal analysis begins by essentially three methods:

a. by establishing a new threshold which may be higher than the DP threshold,

b. by matching fine beam detections on Partition I with coarse beam detections on Partition II for the same signal and eliminating one of the duplicate detections, and

c. by assigning processing priorities to detections which may increase the S/N threshold for particular beams or decrease the probability that the computer will process the signal as the work load increases.

This process of eliminating unwanted detections and selecting the ones to be analyzed in EP is done by MJ Control as shown on Figure 11, a Block Diagram of EP Function.

After being selected for further processing in EP, a detection passes through four separate job steps (Figure 11). In Job Step 1 (SP01), data containing the signal are read into a disk file from a LASA high-rate tape. Subarray beam delays and array beam delays are calculated to form one subarray beam per subarray for all 21 subarrays directed toward the location reported in the detection log. These subarray beams are filtered 0.8 to 2.5 Hz recursively and a primary array beam of all 21 subarrays is formed by using the calculated array beam delays.

In Job Step 2 (SP02) all of the event analysis takes place including event alignment, refinement of location, and parameter estimation (size, arrival time, period, and depth).

The sequence of processing in Job Step 2 is as follows. The primary array beam is cross correlated with each subarray beam in an iterative process to improve the array beam. The final array beam delays are determined after the cross correlation process and the elimination of poorly correlated subarrays. If the cross correlation process fails to improve the beam, the EP system will form two rings of 19 beams with the center beam at the detected location and will select the best beam from them.

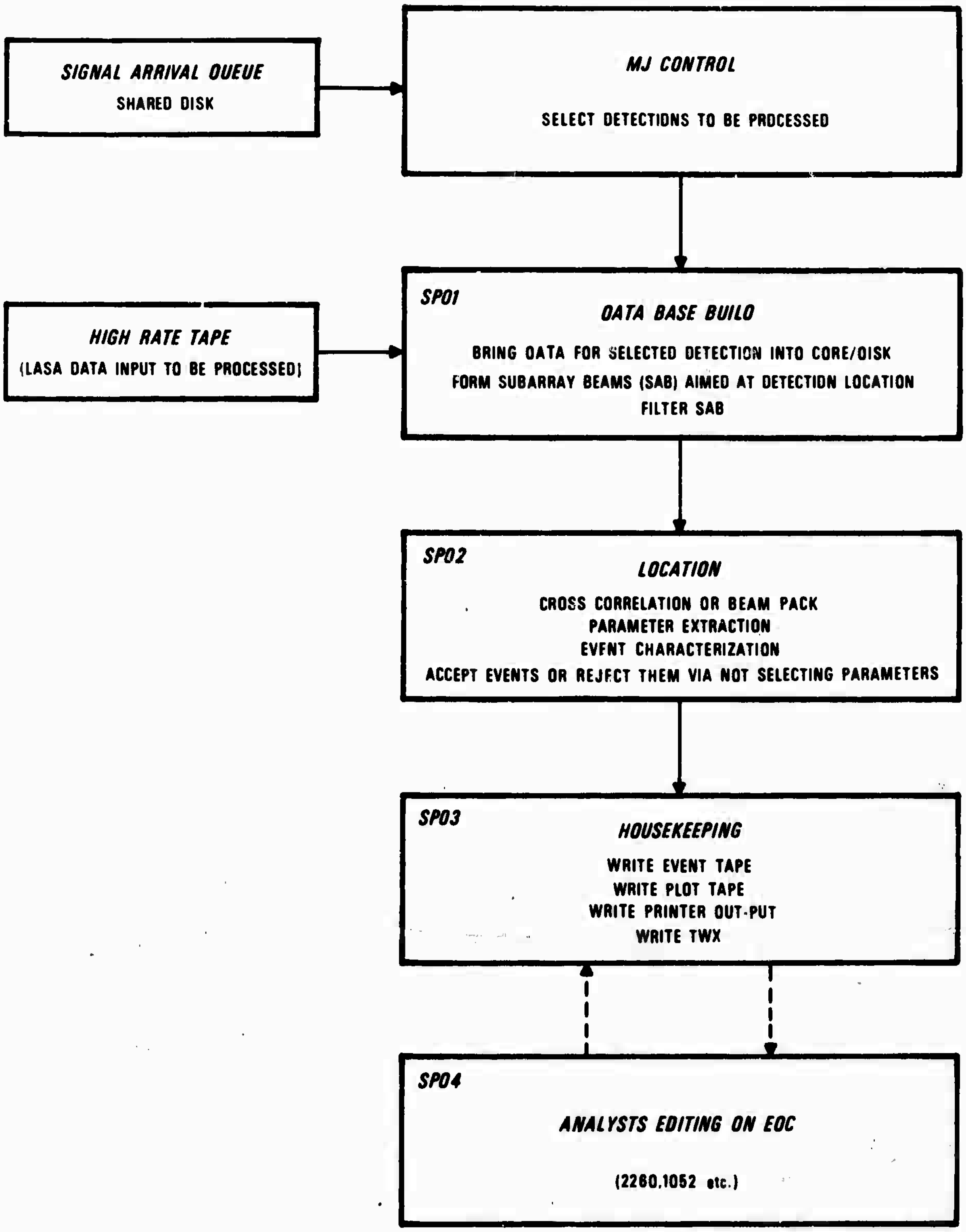

Figure 11. Event processor functions.

After the beam time delays are determined, either from cross correlation or from 19 neighboring beams, the array beam is formed un-filtered subarray beams. Frequency compensation is made with a filter so that the system has a flat response from 0.7 to 2.0 Hz. This is the unfiltered array beam. The unfiltered beam is then filtered, either by 0.6 to 2.0 Hz filter for large signals, or 0.9 to 1.4 Hz filter for small signals. Both unfiltered and filtered beams are used in the extraction of event parameters.

The magnitude and arrival time are determined from the beam power envelope of the filtered array beam. The maximum power value is corrected for the ambient noise power and the magnitude is a logarithmic function of this value. If the event is large, the time of the threshold crossing will be a good approximation of the arrival time. For small events and all later phases, however, the arrival times are determined by fitting the beam power envelope to that of a model event. These model waveforms and envelopes, one for each partition, are stored in the system. The first motion direction is determined from the unfiltered beam by correlating this beam with a reference waveform. This correlation process also finds the arrival time. The event arrival time calculated from the threshold crossing of the filtered array beam is refined by applying the results of the correlation.

Later phases from the same azimuth and distance are sought. If a depth phase is picked, the depth is computed from the P to pP time interval and the

event relocated using the Herrin travel-time table appropriate to that depth. Finally the location of the event is bias adjusted according to a correction appropriate to that region. The correction to be used is determined by interpolating between the three nearest calibrated regions. The results are converted in terms of latitude and longitude, azimuth and location, time and day, and magnitude and depth.

If SAAC operated automatically, then Job Step 3 (SP03) would publish the results of the event analysis from Job Step 2 (SP02) just described. Job Step 3 (SP03) is normally initiated by the operator at the end of each day or after a significant number of processed events has accumulated. In addition to publishing a bulletin of events (LASA Daily Summary) on TWX, Job Step 3 (SP03) writes an event tape, printer output, and a plot tape. The event tape includes filtered and unfiltered beam traces and subarray traces plus event parameters listed on the Daily Summary. The printer output lists all event parameters plus the detection report. The plots show filtered or unfiltered array beams, partial array beams, and the 21 subarray beams with alphanumeric information giving the event parameters.

During the period from February 1 to May 16, 1971, we have not allowed the system to operate automatically. All events processed by Job Step 2 are reviewed by the analysts on the EOC under Job Step 4 (SP04). The analysts verify or correct the results of SP02 and may reject signals that have been accepted by EP.

Queuing problems

EP maintains several files on random disk storage. Like the Signal Arrival Queue in DP, these files are continuously being filled and subsequently emptied for additional entries. EP writes all signal detections listed in the SAQ on the Detection File, a disk file with space for 678 signals. While doing so, EP compares the parameters for each detection with signal-to-noise thresholds and beam priorities, and flags each signal which should be processed.

Next, EP begins its processing of all entries in the Detection File which have been flagged for processing. It stores the required data on disk in an Event Data Set, which consists of unfiltered subarray beams, filtered and unfiltered array beams, and a number of statistical functions and individual variables which are to be used in characterizing the event. One Event Data Set is needed for each signal processed. Available storage can hold a total of 60 Event Data Sets.

After EP analysis is completed, the results are placed in the Unedited Bulletin File, a file containing seismic bulletin information which has not yet been edited by an analyst. The event information in this file includes year, month, day, time of day, source latitude, source longitude, focal depth, method of depth computation, level of confidence for source location, method of location estimate, geographic region number, magnitude, and phase identifier. This

file contains space for 60 events.

Next, the signal information stored in the Unedited Bulletin File and the Detection File is merged and stored in the Detection/Bulletin File. This file, which is accessible to the analyst from the EOC, is limited to 400 lines of data. EP now frees the Detection File and Unedited Bulletin File for other signals.

After the events selected by EP have been reviewed and the event listings have been edited by the analyst, the listings are written on tape and printer, and the waveforms are plotted. At this time the Detection/ Bulletin File and the Event Data Sets are freed for additional events.

The Detection File has space for 678 events. Under current operations, it rarely fills up. When it does, EP stops reading the SAQ which could result in lost detections.

The Event Data Set has space for 60 events. In days of high activity, this space is inadequate to hold 24 hours of signals. If the EP threshold were lowered appreciably, we would have to schedule more than one analyst session per day.

The Unedited Bulletin File has space for 60 events. The comments made for the Event Data Set also apply here.

The Detection/Bulletin File has two partitions, each holding 400 lines. The computer will fill only 384 lines leaving the remaining 16 for extra lines to be added by the analyst in his editing if he wishes.

Each 400 line section terminates at 2400 GMT or when it is full, whichever occurs first. Thus, one section could have only a few entries just prior to 2400 GMT and not accept entries from the new day. When this happens, and it does frequently, the system requires analyst attention in the evening hours, (note that 2400 GMT is 1900 EST) since we insist on analyst editing of all data.

During the period from February 1 to May 16, 1971 we have required an analyst to edit EP outputs prior to publishing the LASA Daily Summary. We have tried to schedule operations so that the analyst would have to be at the EOC in SAAC only once a day, preferably during daylight hours. This schedule is not always possible to maintain. As seismic activity increases or as detection-analysis thresholds are lowered, editing by the analyst is needed more often because the disk storage allocations fill up faster.

CPU utilization in EP

The IBM 360/40B averages 382 seconds per event in its EP analysis. This analysis is subdivided into six functions. Table III below lists these functions and the amount of time spent on each for the LASA data recorded on March 16, 1971.

Detailed tables in Appendix III show the CPU time used by EP for each event it analyzed on March 15th and 16th. The number of events processed was 20 in the first day and 48 in the second day. Although there are great differences in the number of events processed per day,

TABLE III

Computer Time Spent on Various Analysis Functions

Symbol	Function	Time (seconds)	%
SP01	Beamforming	4134.8	22.6
SP02	Correlation	8547.3	46.7
SP03	Beam Packing	1280.0	7.0
SP04	Event Parameter Extraction	2943.9	16.1
SP05	Calibration	1382.3	7.6
SP06	Event Characterization	2.0	.0
		5.1 Hrs.	100.0

Data from EP Analysis of
March 16, 1971

the daily percentage used by each function stayed within 2%. This suggests that the daily percentages will be about the same for weekly or monthly averages.

About 48% of the CPU time was used by the correlation function (SP02). If we bypass SP02 and use beam packing (SP03) to locate every event, 48% of the time will be saved. On the other hand, if we bypass beam packing, the time saved is not as great. Beam packing only uses 7% of the CPU time, 30% to 50% of which is required whether or not beam packing is the method of location. It should also be noted that the correlation method requires a high degree of signal coherence and thus breaks down on low amplitude signals where the ambient noise comprises a significant part of the signal. If beam packing were used on all events, the time required for SP03 would increase to about 10%. Hence relying on beam packing exclusively will save an estimated 40% to 45% of the CPU time.

<u>Detection log reduction, analyst review and edit procedures</u>

The detections that were written on the shared disk (SAQ) by the DP are read by the EP and sorted to determine which ones are to be processed as events. This procedure is referred to as detection log reduction. The several criteria which a detection must meet are discussed in the following paragraphs.

The first criterion is <u>thresholding</u>. A S/N threshold is used in the EP independent of the DP threshold, although the value of the S/N is that determined in the DP. Unlike the 3/3 or 4/4 logic used in DP, this is a

simple pass or fail threshold based on the maximum signal level. From February 1 through March 29, the EP threshold was set at 16 db; for the remainder of this evaluation report it was set at 14 db. The DP threshold was set at 10 db during the entire period. The following table shows how many detections were rejected by EP due to the difference in threshold settings. The data are grouped to reflect changes in the mode of operation but are in chronological order. Data for days which were split between different modes of operation have been dropped from the sample. As can be seen from Table IV, the percentage of detections that fail EP threshold depends not only on the difference between the DP and EP thresholds, but also on the detection logic being used. Over the period of this evaluation, a total of 77% of the DP detections were rejected by EP for this reason.

Figure 12 summarizes the daily detection-rate history for the period of this evaluation report. The upper histogram indicates the daily number of detections made by DP (scaled to a 24 hour day) and passed to EP via the SAQ on the shared disk pack. Milestones which affect the detection rate are indicated at the top of Figure 12. On day 49 (February 18), the detection logic was changed from 3/3 to 4/4 with an obvious change in the number of detections. The daily rate for 3/3 is 1129. Days 50 through 53 were mixed 3/3 and 4/4 due to operational difficulties with the DP system. From day 54 (23 February) through 136 (16 May), the average daily detection rate for 4/4 is 553. An exception, due

TABLE IV

Detection Reductions due to EP Threshold

Sample Number	Number Days	Number Detections	Detection Logic	Threshold (db) DP	Threshold (db) EP	Number Failing Threshold	Percent Failing Threshold	Number EP Detections Remaining
1	17	16,144	3/3	10	16	13,804	86	2,340
2	40	20,785	4/4	10	16	16,815	81	3,970
3	48	26,142	4/4	10	14	18,001	69	8,141
	105	63,071				48,620	77	14,451

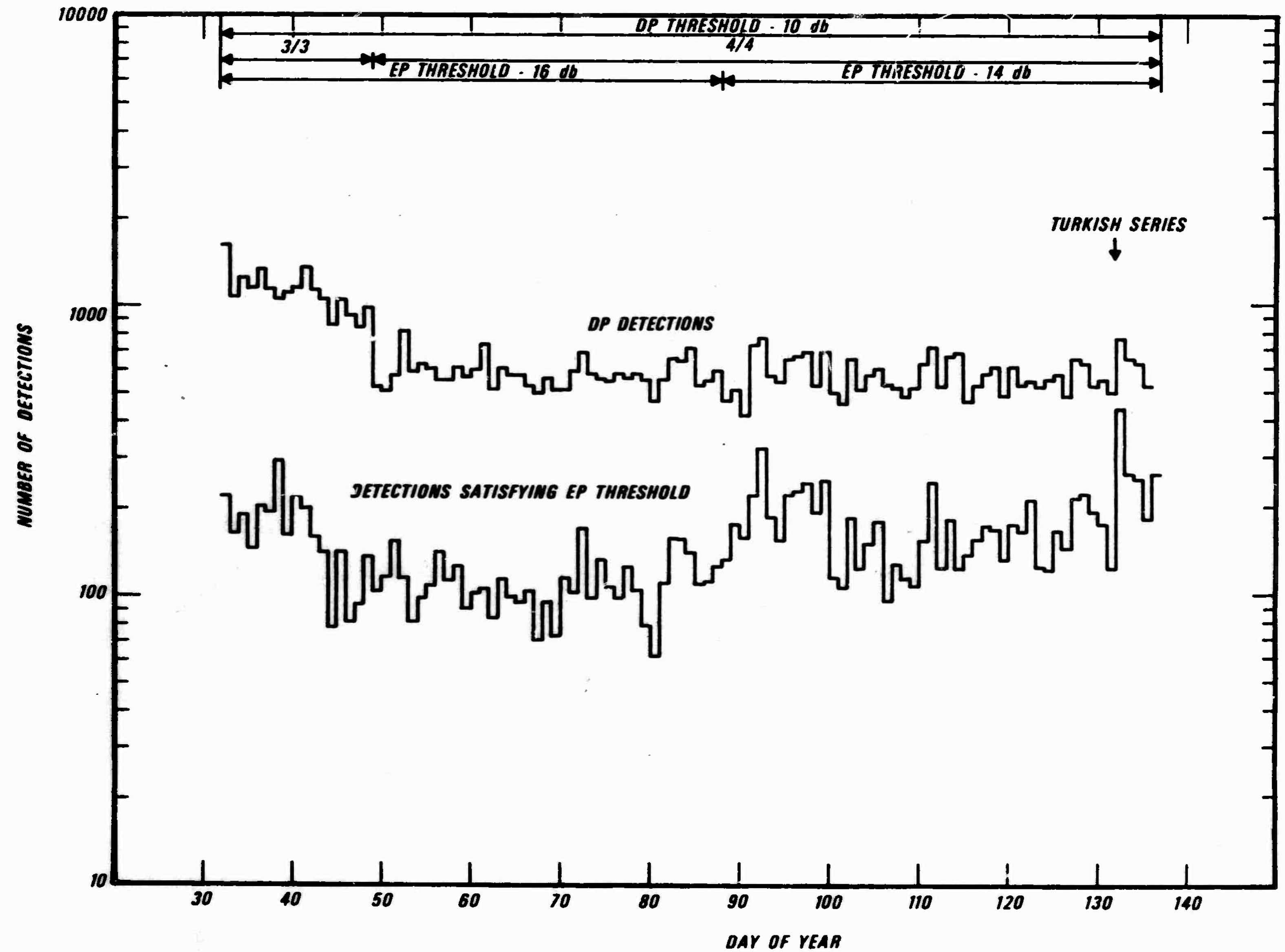

Figure 12. Daily detections above DP and EP thresholds

to a Turkish series of earthquakes, is day 132 (12 May) with 779 detections. The lower histogram shows the number of detections which remain after applying the basic EP thresholding criteria described earlier in this section. Using 3/3 detection logic and an EP threshold of 16 db, the average daily number of detections is 167. For 4/4, the average daily rate is 110. When the EP threshold is changed to 14 db (DP still using 4/4 logic), the average daily rate is 168. This rate does not include the Turkish series of May 12 which has 425 detections.

The second criterion for rejecting a detection concerns duplication. As stated earlier in this report, there are two partitions of beams formed in the DP; the General Surveillance Beams - Beam Set 140, Partition II - and the Selected Surveillance Beams - Beam Set 133, Partition I. These two partitions are treated independently by DP; hence those events occuring in a region at which beams for both beam sets are aimed will be detected by both. Since detections occur at approximately the same time, they are readily recognized as duplicates. Table V indicates how many detections were omitted using this criterion during the period covered in this evaluation.

The next rejection criterion is to associate those detections occurring within a minute or so after the initial P phase as possible later arriving phases of the same event. This is accomplished by grouping the detections from the same general geographic area

TABLE V

Detection Reductions due to Duplicate Partitions

Sample Number	No. Days	No. EP Detections	No. Duplicate Detections	Percent Duplicates	No. Non-Duplicate Detections
1	17	2,340	626	27	1,714
2	40	3,970	980	25	2,990
3	48	8,141	2,013	25	6,128
	105	14,451	3,619	25	10,832

to a Turkish series of earthquakes, is day 132 (12 May) with 779 detections. The lower histogram shows the number of detections which remain after applying the basic EP thresholding criteria described earlier in this section. Using 3/3 detection logic and an EP threshold of 16 db, the average daily number of detections is 167. For 4/4, the average daily rate is 110. When the EP threshold is changed to 14 db (DP still using 4/4 logic), the average daily rate is 168. This rate does not include the Turkish series of May 12 which has 425 detections.

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The next rejection criterion is to associate those detections occurring within a minute or so after the initial P phase as possible later arriving phases of the same event. This is accomplished by grouping the detections from the same general geographic area

and selecting only one of them; the others will be processed as later arrivals and are deleted from the list of detections to be processed. Table VI gives the results of applying this criterion. The original 63,071 detections have been reduced to 6,796 at this stage of the process, a reduction of 89%.

The last criterion is a complex priority-thresholding system. Each beam defined in the DP has an input parameter priority flag with a value of one, two, or three. These flags determine the actual EP threshold for a given detection based on the beam that detected it. Of course, the basic EP threshold must also be met simultaneously. The signal-to-noise ratio threshold for beams with the priority flag equal to one is 10 db; for a flag value of two, the threshold is 16 db; and for a flag value of three, it is 22 db. Thus, if the basic EP threshold is set to 14 db, a detection on a beam with the priority flag equal to one will be processed if the signal-to-noise ratio exceeds 14 db. However, detections on beams with the flags set to two must exceed 16 db, and detections on beams with the flags set to three must exceed 22 db in order to be retained for further processing.

A detection which has satisfied all the above criteria is now assigned a processing priority. To determine this priority, a ratio R is first formed from the observed detection signal-to-noise ratio and the assigned signal-to-noise ratio based on the beam priority flag. R is then compared to fixed values within EP, and the processing priority set as shown in

TABLE VI

Detection Reductions due to Later Phase Logic

Sample Number	Number Days	No. Non-Duplicate EP Detections	No. Deleted as Phases	Percent Deleted	No. Detections Remaining
1	17	1,714	709	41	1,005
2	40	2,990	1,159	40	1,791
3	48	6,128	2,128	35	4,000
	105	10,832	4,036	37	6,796

TABLE VII

Processing Priority Assignments

Condition	Priority
$R < 1$	10 (Not to be processed)
$1 < R < 1$	4 (Trivial case)
$1 < R < 2$	3
$2 < R < 1024$	2
$1024 < R$	1

Table VII. All priorities, except 10, will be processed unless an input maximum time-lag parameter has been exceeded. The time-lag is defined as the current real time on the EP internal clock minus the detection time and is determined for each detection. When the lag exceeds the input parameter, the detection will not be processed. The time-lag feature and the priority system are efforts to prevent EP from being swamped, as when a major aftershock sequence occurs. All detections occurring on beams with priority flags set to one bypass the processing priority R logic and are processed at the basic EP threshold; however, the other four criteria must still be satisfied.

The number of detections rejected under the priority-threshold criterion is shown in Table VIII. The detections deleted due to time-lag are not included in Table VIII but rather are included with the system failure statistics discussed later in this section. Note that the detection rate for the priority-threshold criterion nearly doubles when the EP threshold is changed from 16 db to 14 db (Sample 2 to Sample 3 in Table VIII). The reason for this increase is that detections on beams with the priority flag set to two still have to meet the 16 db criterion, even though the basic EP threshold is lowered to 14 db.

The original 63,071 detections by DP have been reduced to 4096 (six percent of the total) selected to be processed by the EP. Of these, 429 (approximately 10%) failed to be processed because of abnormal terminations of either the EP system or the DP system,

TABLE VIII

Detection Reductions due to Priority-Thresholding Logic

Sample Number	Number Days	Number Detections	No. Deleted by Priority-Threshold	Percent Deleted	No. Detections Selected for EP
1	17	1,005	314	31	691
2	40	1,791	498	26	1,293
3	48	4,000	1,888	47	2,112
	105	6,796	2,700	40	4,096

or because the time-lag limit was exceeded. When the DP abnormally terminates, it fails to inform EP of the tape reel number it is currently recording; hence, EP does not know what data tape to ask for and must assume that none exists. For EP abnormal terminations; events which are processing when the system terminates (other than by a special command) are lost. Although the events lost on EP termination are still listed as having been processed, they are easily identified because no event output is generated.

When all detection criteria have been applied, the results are as shown in Figure 13. The average daily rate for 3/3 detection logic and EP at 16 db is 46; for 4/4 logic and EP at 16 db, the rate is 35; and for 4/4 logic and EP at 14 db, 39. The observed numbers, not scaled to 24 hours, are 38, 31, and 36 detections per day. These are the detections that are considered as valid events by the automated SAAC/ISRSPS DP-EP combined systems. Near the end of April, it was noticed that many detections within P-wave range were not being processed due to the priority-thresholding logic described above. During May, we utilized a manual input procedure (termed rerun) to force EP to process these detections. When the reruns are added to the EP processed events just discussed, the observed average daily rate for 4/4 and EP at 14 db becomes 73 and the 24 hour rate becomes 77. The beam priority flags have since been changed so that the EP will now pick up these events automatically.

At this point, it is necessary to mention that some detections are not processed but should have

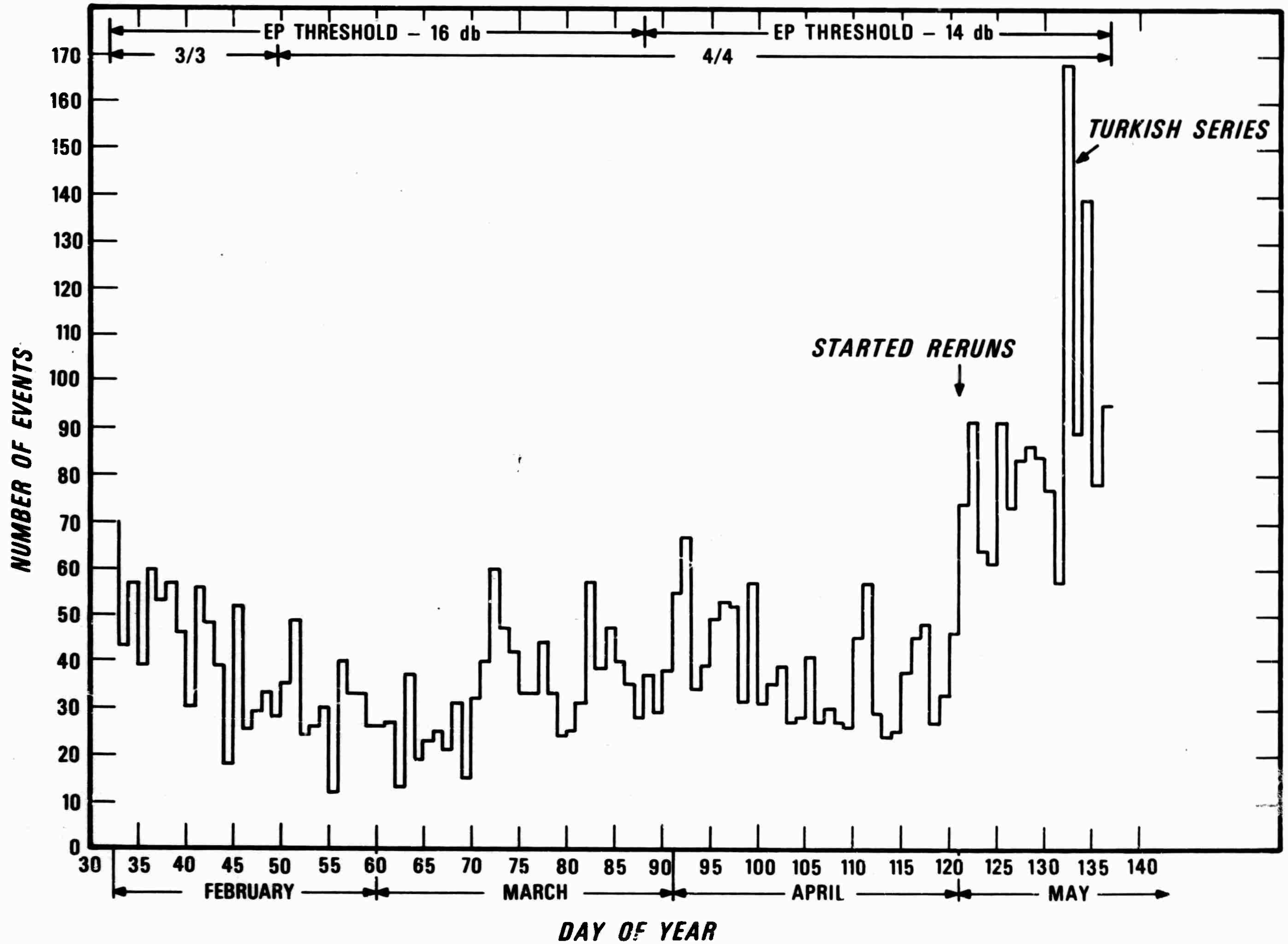

Figure 13. Daily events reported by EP.

been for reasons other than priority-thresholding logic. There are two reasons for this. The first one is hardware or software failure which was mentioned previously. The second is a condition called velocity failure. Velocity failure should mean, and was intended to mean, that the computed velocity is not compatible with the standard travel-time curves.

There is a bug in the program such that many actual events that are we l within range from LASA fail due to velocity failure. These failures are believed to average about three or four per day, however, as many as eight have been observed. Table IX shows the total number of velocity failures, both real and erroneous, that were observed during this evaluation period. Also included are the 429 events which were lost due to system failure and/or time-lag.

The samples in Table IX are as follows: The first 16 days of May have been separated from the third sample of the previous tables and listed as a fourth sample. The fifth sample shown also covers the first 16 days of May but represents the reruns that were made to cover the detections which were deleted by the priority-thresholding criterion but which the analyst thought could be possible valid events.

It is not surprising that the percentage lost due to velocity failure is higher on the reruns, as most of the priority-thresholding failures occur at

TABLE IX

Detection Reductions Due to System and Velocity Failure

Number Days	Number Events Selected for EP	Number lost by System Failure	Percent Lost	Number lost due to Velocity Failure	Percent Lost	Number EP Events
17	691	67	10	93	13	531
40	1,293	119	9	168	13	1,006
32	1,300	162	12	186	14	952
16	812	81	10	118	15	613
16 (Rerun)	614	0	0	128	21	486
Total	4,710	429	9	693	15	3,588

distances near the limit of the P range.

During the first eleven days of May, when reruns were being made and before the large Turkish series occurred, the SAAC/ISRSPS in an automatic mode was detecting with a 4/4 logic with the EP threshold at 14 db. Assuming that the erroneous velocity failure problem, which will be corrected, adds three events per day, the rate of automatically produced events is 64 for a 24 hour period.

As we have thus far operated the system, it has not been allowed to list the events automatically. Rather, all events have been reviewed and edited by an experienced seismic analyst working at the EOC.

The EOC consists of two display units, one for listing parameters and one for displaying waveforms, and two input units for instructions and information, one a typewriter style keyboard and the other a configuration of switches. The EOC is tied to the 360/40B computer and is an integral part of the EP system. After the EP completes its process, all events are available to the EOC where the analyst checks them for validity of the detection and for correctness of the listed parameters. The parameter analysis is discussed in the Event Parameter Analysis section of this report. The validity of the events, as judged by the analysts, is discussed here.

First, detections are removed that were not reviewed due to system queue limitations, to lack of

time on the EOC caused by hardware and software failures, and to varying analyst efficiency. Using the same sampling intervals as in Table IX, Table X shows how many events were not reviewed as a function of calendar time. Clearly, as the machine operators learned the system, and as the analysts became familiar with array beam data, with the characteristics of LASA signals and noise, and with the operation of the EOC, the efficiency increased to a point where almost all data were handled when the DP system operated at 10 db with 4/4 logic, the EP at 14 db, and when the activity rate remained near the average levels observed in May 1971. It should be recalled that during the first sampling interval the EP was using a 3/3 detection logic with a detection rate nearly double the rate for 4/4. For 3/3 logic, the queues fill up in half the time; hence, the analysts must spend more time at more frequent intervals on the EOC.

The last column in Table X contains pertinent data for checking the effectiveness of the EP logic in separating the valid detections from either local event-generated signals, side lobe detections, or noise bursts. These three conditions are discussed separately.

The term local events as used here means all non-teleseismic events with apparent velocities less than about 8 km/sec. Because of the characteristics and energies of these events, many teleseismic beams are triggered at the same time. Hence, one local event can cause many detections scattered over widely separated regions. Because of the scatter, the

TABLE X

Event Reductions Due to Operational Time Limitations

Number Days	Number EP Events	Number Not Reviewed	Percent Not Reviewed	Number Reviewed
17	531	349	66	182
40	1,006	83	8	923
32	952	37	4	915
16	613	2	0	611
16 (reruns)	486	0	0	486
	3,588	471	13	3,117

criteria used by EP for detection log reduction, as described earlier, fail to eliminate all of these detections. As a result, several events are formed by EP from one local event. For the evaluation period, the analysts deleted 310 events of 3117 (10%) due to local events.

The detection logic used in the DP cannot completely eliminate side lobe detections. Also, side lobe detections are frequently so widely separated that they will not be associated as such by EP. Therefore, more than one event may be listed by the EP for a given signal. The analysts deleted 288 for this reason (9% of the events reviewed by the analysts).

Later arriving phases such as PP, PcP, and PKKP are sometimes processed as separate events by EP. The system has no capability for associating later phases (later than approximately one minute). The analyst is also limited due to array aperture; thus only 73 events (2%) were deleted for this reason.

Another reason for deleting events is that DP and EP may create events when there are data line transmission problems or data dropouts. Again, this is only 2% of the events (64).

The greatest single reason for omitting events is due to weak signals (not visible to the analyst for confirmation), noise bursts, or the inability of the EP to align the subarray waveforms, even though signals are present on several subarrays. Quite often, no matter how many times an event is forced back through the system to try to pick up an originally

misaligned event, the EP will not properly align the waveforms.

As the threshold is lowered, the percentage of weak signals increases. But as the analysts become more experienced with array processed data and more familiar with the characteristics of LASA noise, they tend to confirm and accept smaller events. The data in Table XI show a decrease in the analyst's rejection rate with time (the reruns in May are a special case and really represent the analyst's efficiency in determining which detections to process rather than in determining which are events).

After imposing all deletion criteria to the EP, 1512 valid events were transmitted to interested users via teletype. Figure 14 shows the number of events that were transmitted each day during the evaluation period, and Figure 15 shows the percentage of the day for which the EP results were reviewed. It can be seen that the number of events increases moderately over the entire period. On May 1, when reruns were started, the number increases even more. On May 12, the Turkish series occurred causing the number of events to be far above the normal work load. This caused a strain on the queue system and on the time for analysis because of operational difficulties and not because of hardware and software design. Figure 16 shows the percent of each day that the analysts spent on the EOC. Although the degree to which the system can be pushed is presently unknown, it is known that a series as large as that from Turkey can be handled. The effects of the various deletion criteria are recapitulated in Table XII.

TABLE XI

Event Reductions Due to Weak Signals

Number Days	Number Events Reviewed	Number Omitted for Weak Signal	Percent Omitted
17	182	68	37
40	923	266	29
32	915	230	25
16	611	81	13
16 (reruns)	486	221	45
	3,117	886	28

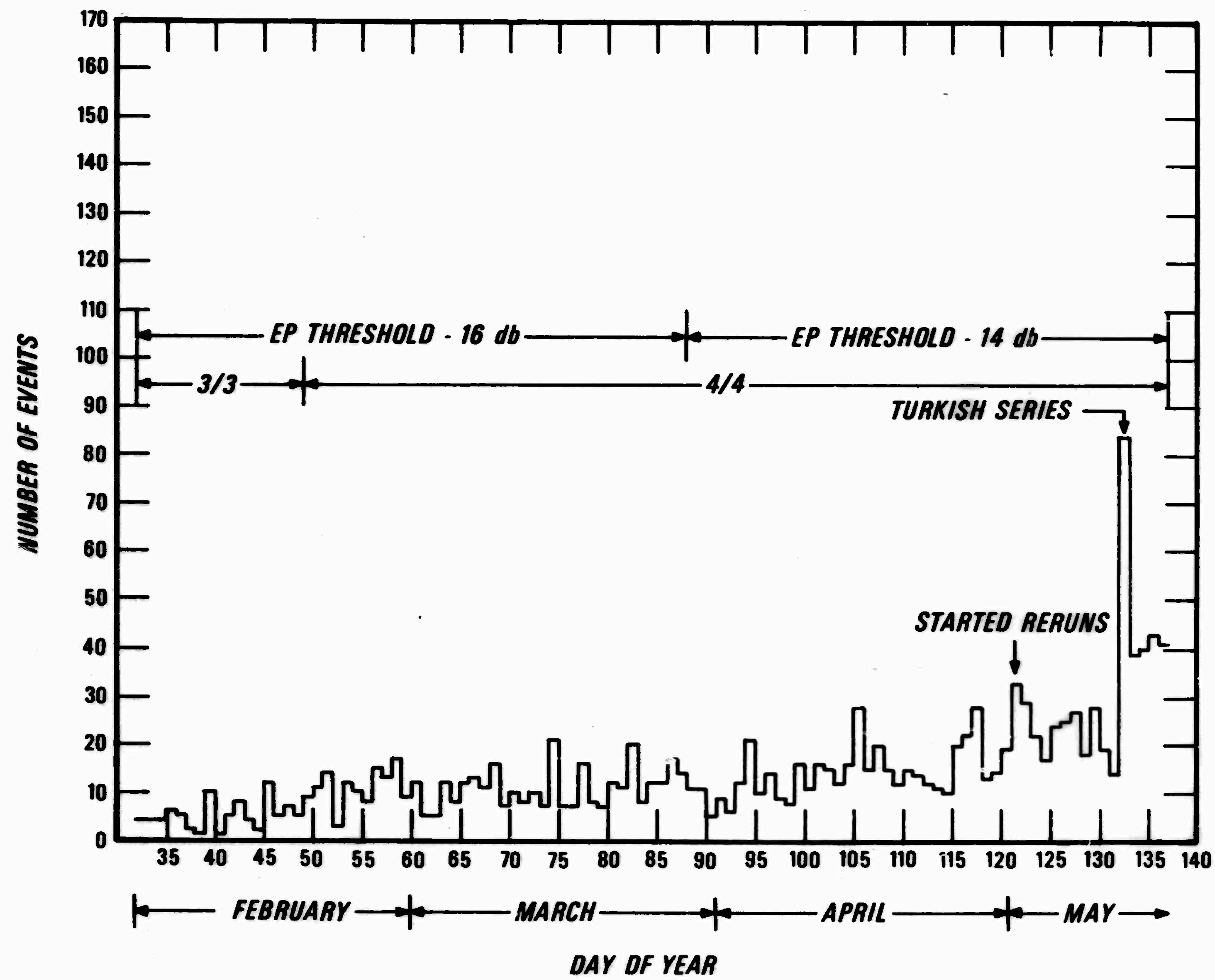

Figure 14. Events reported on LASA Daily Summary.

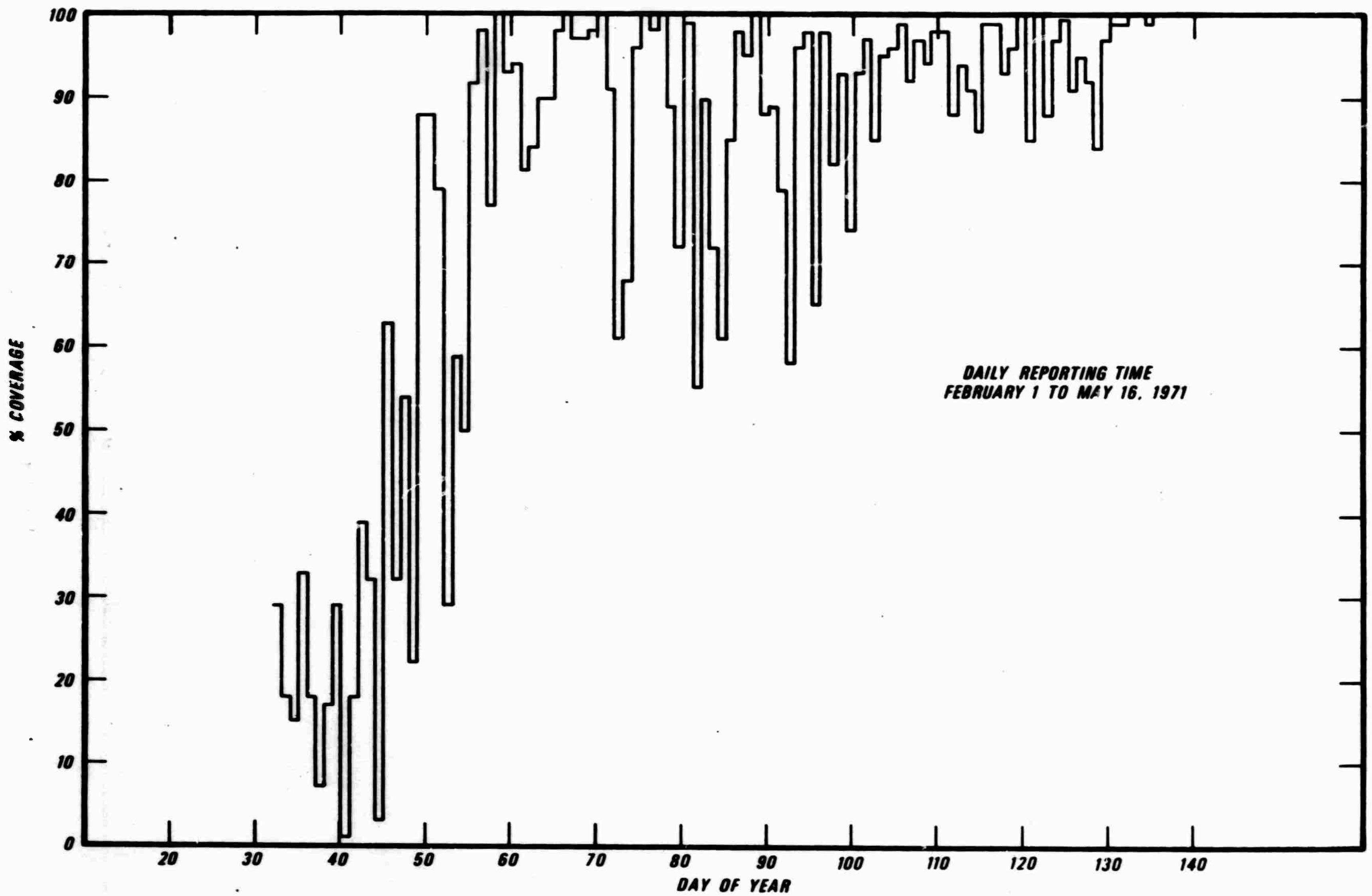

Figure 15. SAAC Summary event reporting time (percent coverage,.

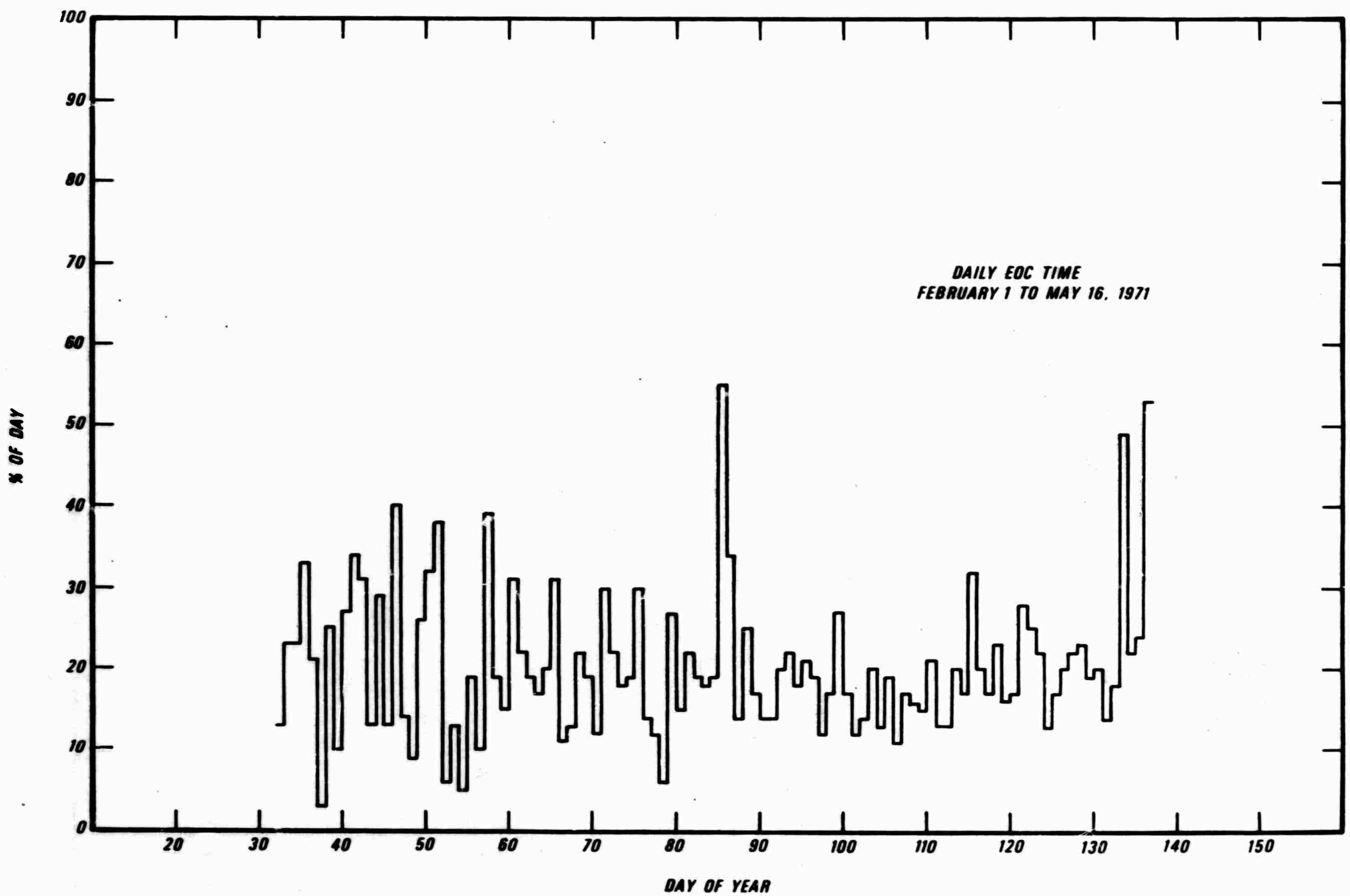

Figure 16. Event analysis reviewing time on the operations console (EOC).

TABLE XII

Summary of Detection Log Reduction
and Analyst Review and Edit Procedures

Feb 1 - May 16, 1971

Number of DP detections	63,071	
Basic EP threshold failures	- 48,620	(77%)
	14,451	
Duplicate detectiors	- 3,619	(25%)
	10,832	
Later-phases	- 4,036	(37%)
	6,796	
Priority-threshold failures	- 2,700	(40%)
Selected for EP (6.5% of detections)	4,096	
Reruns	+ 614	
	4,710	
Computer malfunctions	- 429	(9%)
Velocity failures	- 693	(15%)
EP system events (5.7% of detections)	3,588	
Non-reviewed events due to time limitations	- 471	(13%)
	3,117	
Local event activity	- 310	(10%)
Side lobe detections	- 288	(9%)
Later phases	- 73	(2%)
Data Dropouts	- 64	(2%)
Weak or misaligned signals	- 866	(28%)
Events reported on Daily Summary (2.4% of detections)	1,516	

V. EVENT PARAMETER ANALYSIS

Arrival time and first motion direction

EP computes an approximate arrival time from a power envelope (a running 14 point sum of the squared beam trace) of the filtered array beam. By correlating this envelope with the envelope of a model event (one for each partition), the arrival time can be approximated. Next the unfiltered array beam is correlated with a reference waveform near the approximate arrival time. This correlation determines a refined arrival time estimate and the direction of the first motion. For more detail, see ISRSPS Programming Manual, REF 110, section 12-3-6.

Figure 17 shows a plot of arrival time errors (EP - Analyst in seconds) versus signal amplitude in millimicrons for 434 events listed by SAAC in the May 1st to May 16th LASA Daily Summaries. For all events the mean arrival time error is + 0.25 seconds with a standard deviation of 1.19 seconds. For large signals (EP amplitude greater than 10.0 millimicrons) EP arrival time errors average + 0.12 seconds with a standard deviation of 0.73 seconds. Thus arrival time estimates by EP are better for larger signals.

Dominant frequency and period

An analyst estimates the period of a P wave by measuring the time interval between the zero crossings for the full cycle where he has made his peak-to-trough

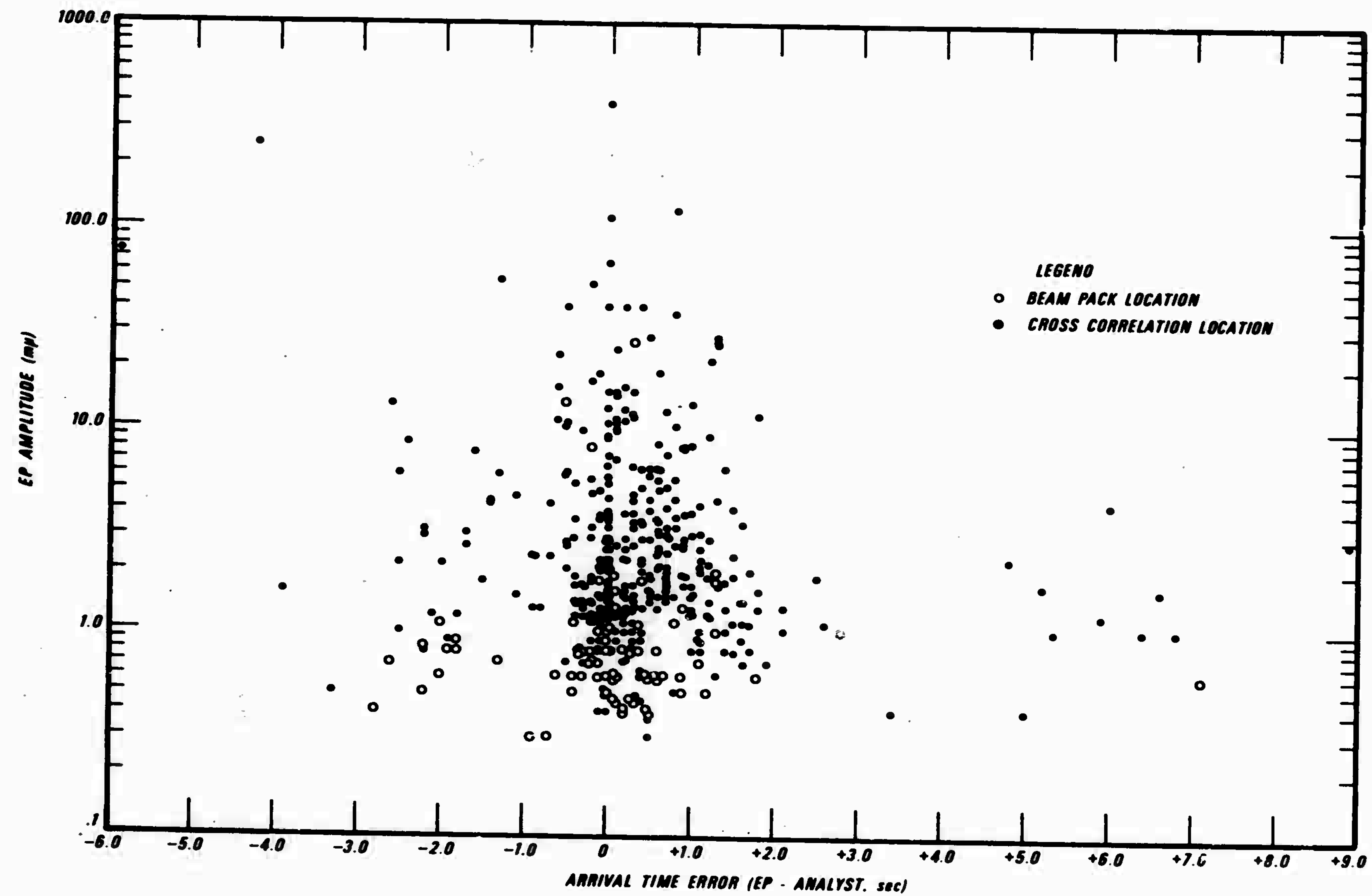

Figure 17. Arrival time errors vs signal amplitude.

amplitude measurements. In contrast, EP estimates the dominant frequency of a signal by computing a power spectrum of the data over 256 points or 25.6 seconds centered about the time of maximum power on the detected signal, (P) phase. Before taking the Fourier transform, a parabolic weighting function is applied to the data ± 1.5 seconds about the center position with all the data outside of this interval zeroed out. This transaction in time is equivalent to a smoothing of the power spectrum. Since the data were filtered, either 0.6 - 2.0 Hz or 0.9 - 1.4 Hz, and the data outside the weighting function are masked, there are actually three seconds of filtered data present. The resolution of the power spectrum is accordingly limited. For more detail, see ISRSPS Programming Manual, REF 110, section 12-3-6.

Figure 18 compares the analyst versus the EP measurements of period for 423 events. EP measures signal periods approximately + 0.1 sec larger than the analysts. Figure 19 compares the EP minus analyst differences in period measurements with the amplitude of the signal in millimicrons. This chart shows that for signal-to-noise ratios greater than 5 (the only events EP processes), the EP-Analyst period differences are essentially independent of signal size.

Signal size and magnitude comparisons

The analyst determines signal amplitude by measuring the largest peak-to-trough half-cycle within the first few seconds of the P waveform and dividing by 2 for a zero-to-peak estimate. EP determines signal

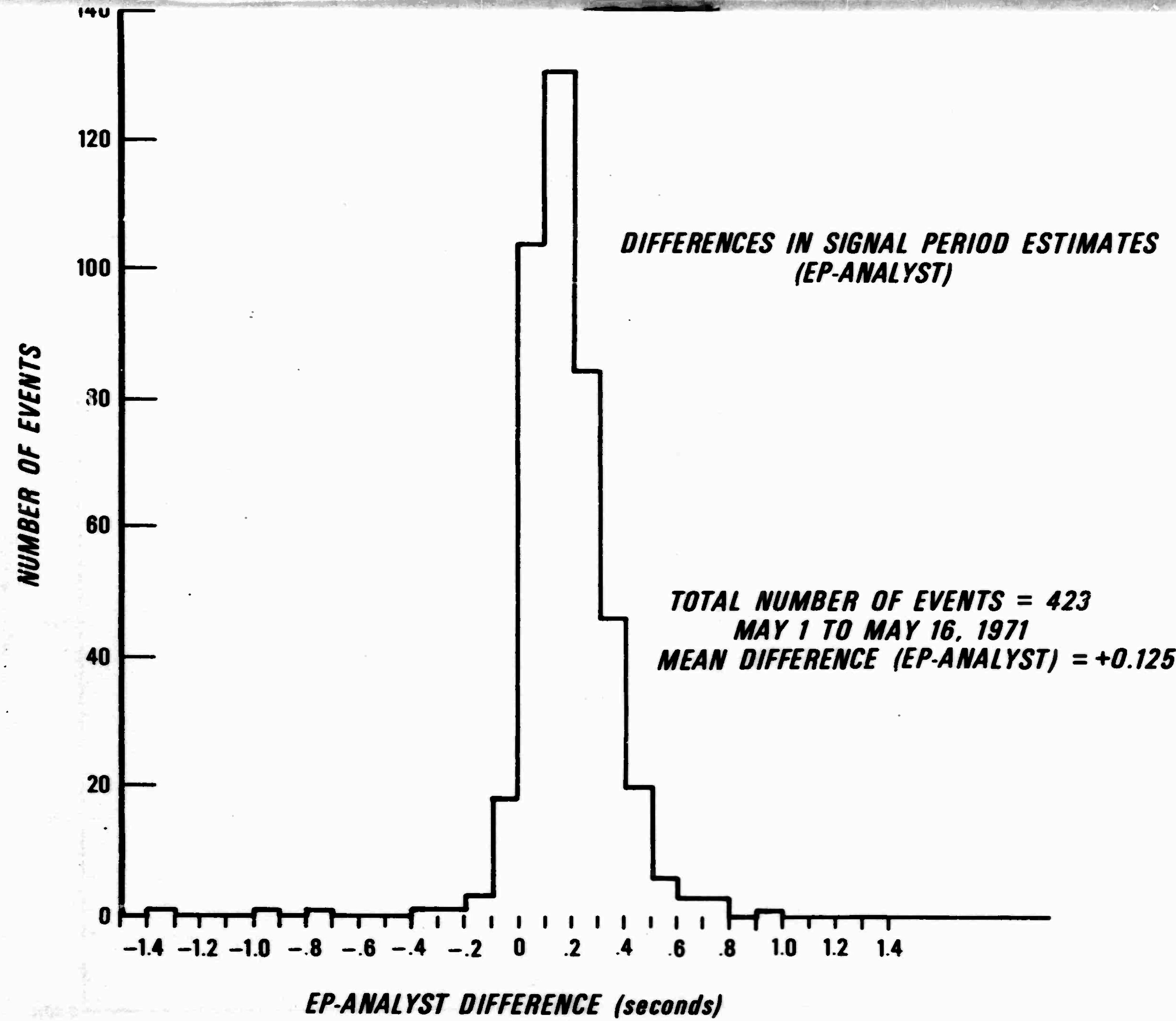

Figure 18. Differences in signal period estimates (EP-Analyst).

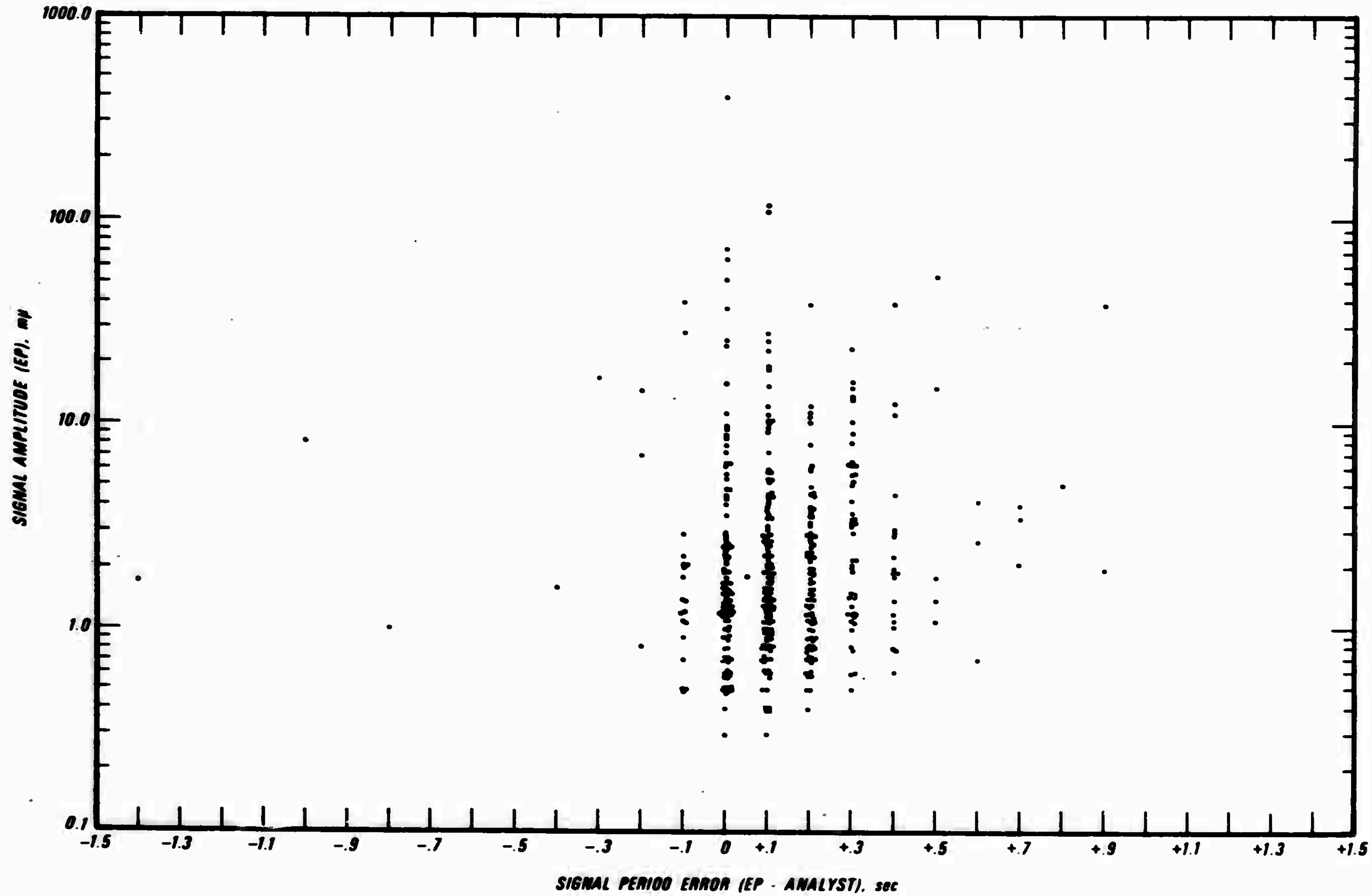

Figure 19. Signal period error (EP-Analyst) vs signal amplitude.

amplitude indirectly from a power spectra computation, the same one, described in the previous section, used to compute the dominant period of the signal. The square root of the peak power in this spectrum is the estimate of signal amplitude. The amplitude (A) and period (T) estimates are adjusted by empirical constants so that the adjusted A/T ratio will lead to an earthquake magnitude value that agrees on the average with the NOS magnitude values. For more details on the EP A/T estimates see "Kinetic Energy Estimates of Seismic Magnitude", IBM Experimental Test Results, ESD-TR-68-424, June 1968.

The analyst computes body wave magnitude, m_b, from measurements of the amplitude (A) in millimicrons and the period (T) in seconds,

$$m_b = \log(A/T) + B$$

where B is a correction factor based on event range and depth.

EP computes body wave magnitude from the formula,

$$m_b = 0.5 \, \mathrm{Log}_{10} |\langle E_s(t) \rangle|_p + Q(\Delta,h) + K + S$$

where E_s = instantaneous kinetic energy per unit mass in joules/kg., K = 6.0 - log π = 5.502502, and S = the residual station bias. E_s is computed from the sum of squares (14 points) or 1.4 seconds starting at the first arrival

of the signal on the filtered array beam. The final correction factor $Q(\Delta,h)$ is added after the depth and distance are determined. $Q(\Delta,h)$ is the same as B in the analysts magnitude computation.

The amplitude, A, is computed from the uncorrected magnitude,

$$A = T(10^{AMAX+3})$$

where T = the dominant period and AMAX = the uncorrected magnitude. The correction factor of 3 is added to convert the amplitude from microns to millimicrons.

For a detailed description see IBM Scientific Experiment Test Results - Kinetic Energy Estimates of Seismic Magnitude, June 1968, ESD-TR-68-424.

Figures 20 and 21 compare the EP estimates of the signal amplitude-period ratio (A/T) with the conventional A/T estimates by the analysts for the same signals displayed on the EOC. We expected the A/T estimates by EP to be equal to those of the analyst;

$$y = (A/T)_{EP} \cong a \cdot (A/T)_{ANALYST} = ax.$$

For 423 events listed by SAAC in May 1971, we find

$$LOG\ (y/x) = LOG\ (a) = .0306 \pm .1334.$$

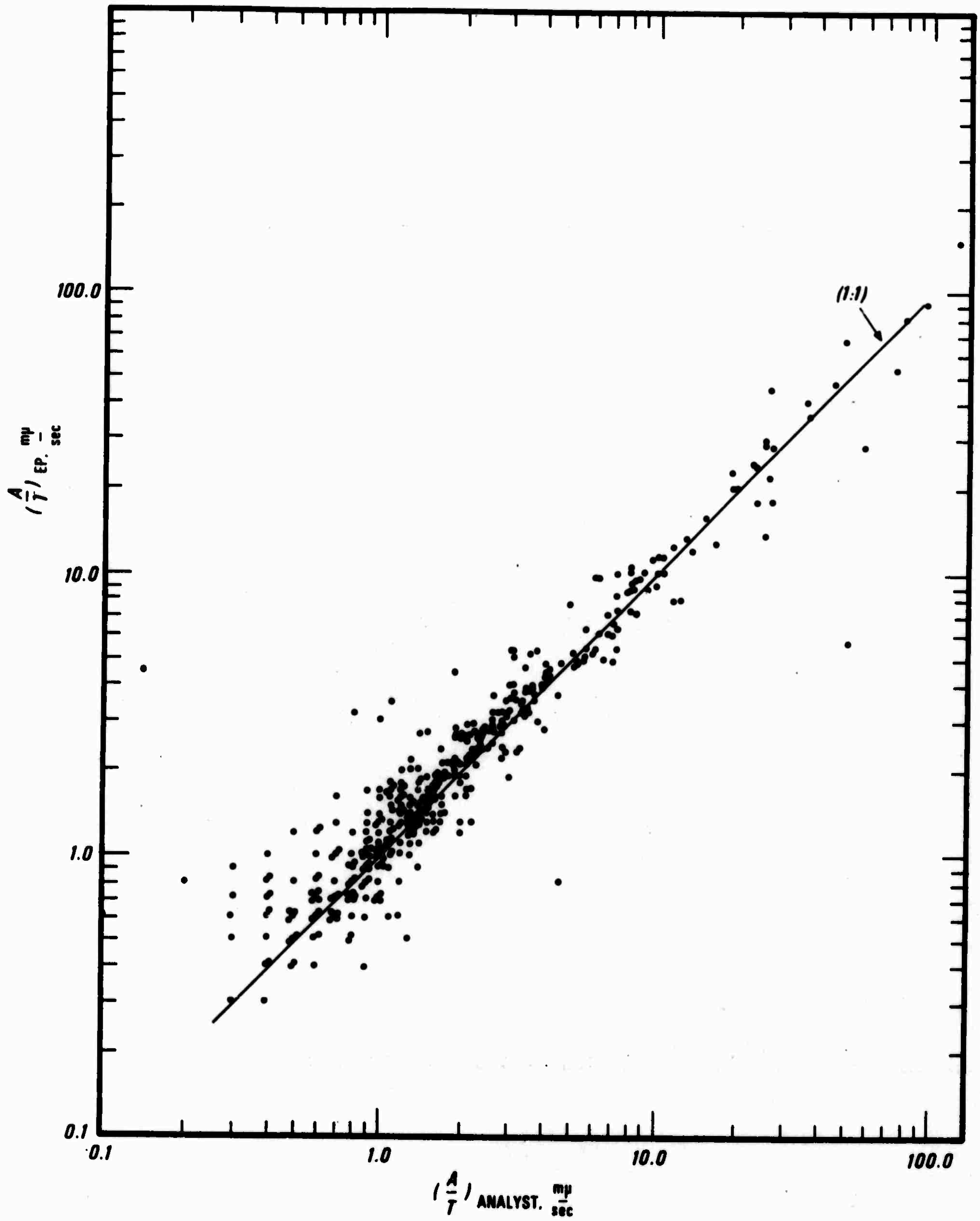

Figure 20. Comparison of A/T estimates (EP vs analyst).

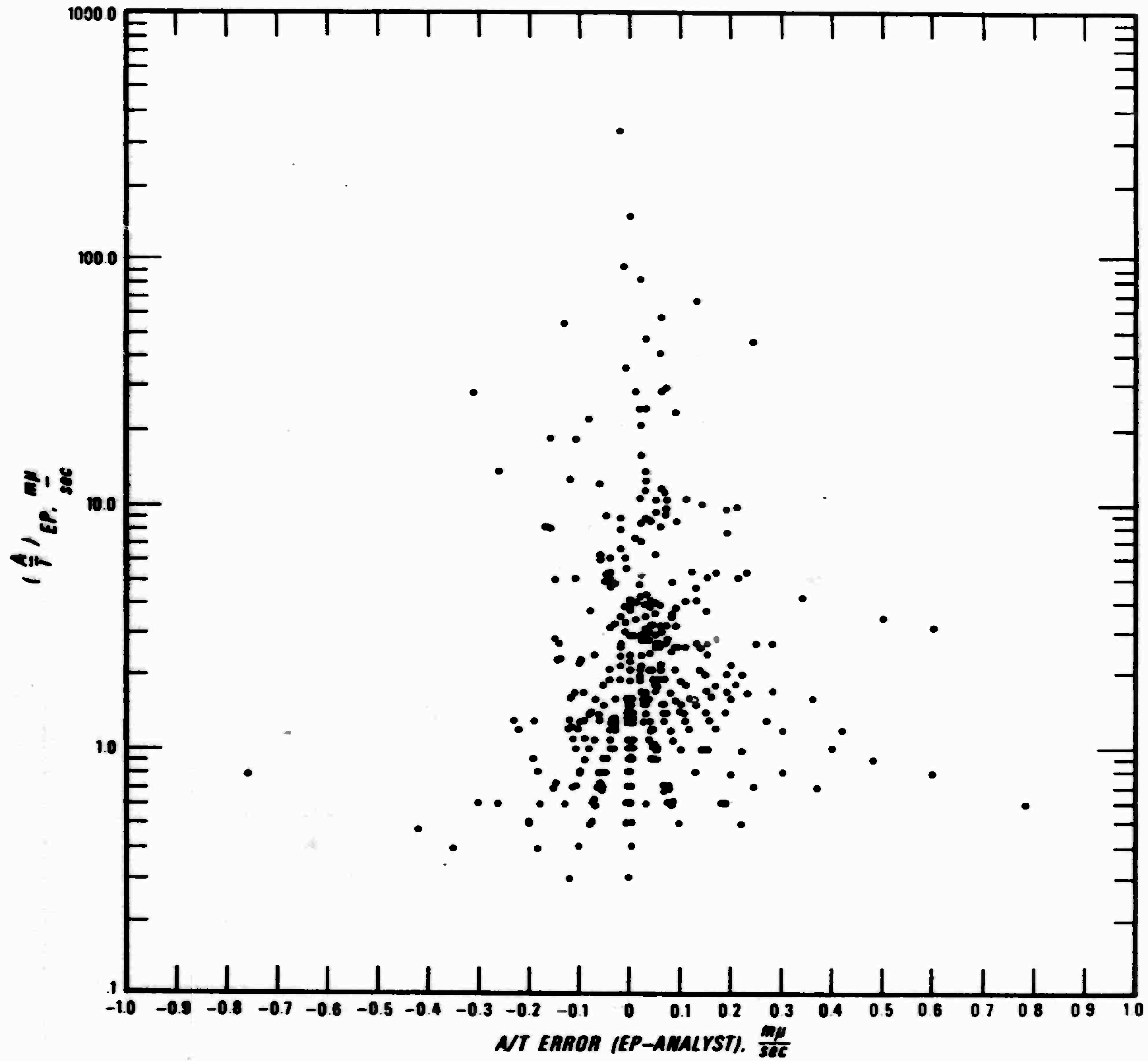

Figure 21. A/T error (EP-Analyst) vs signal size ($(A/T)_{EP}$).

The difference of the EP and analyst body wave magnitude estimates will then be

$$m_{b\text{-}Ep} - m_{b\text{-}ANAL.} = \text{Log}\left[\frac{(A/T)_{EP}}{(A/T)_{anal.}}\right] \cong .03 \pm .13.$$

Thus the EP body wave magnitudes have a mean about equal to the analyst magnitudes but will vary (one standard deviation) from 0.1 magnitude units low to 0.2 magnitude units high. The increased scatter at low A/T values is due to quantization resolution and analyst estimation difficulties.

Figure 22 compares magnitude estimates for 365 events listed in the LASA Daily Summary from February 1 to May 16, 1971 and which were also reported by NOS. The LASA magnitudes in terms of NOS magnitudes for these events are given by

$$M_L = 0.867M_{NOS} + 0.663.$$

Thus LASA magnitudes greater than 5.0 tend to be slightly lower than NOS magnitudes and LASA magnitudes less than 5.0 tend to be slightly higher, although as shown on Figure 22, there is a scatter of $\pm$ 0.5 magnitude.

Depth estimates

Positive identification of depth phases, pP and sP,

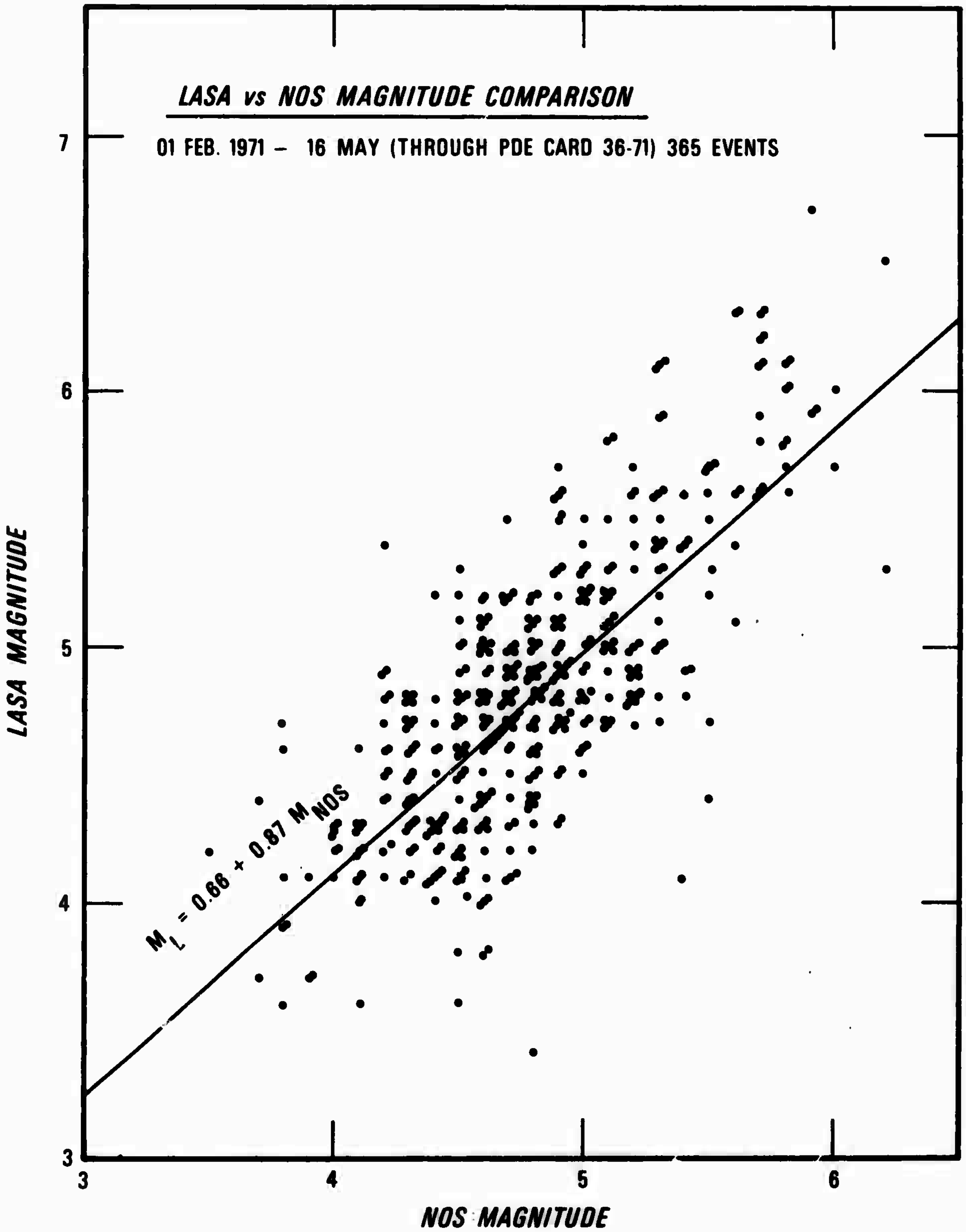

Figure 22. Comparison of LASA and NOS magnitudes.

requires observing the known increase of the P to pP and P to sP time intervals with distance. Thus a single station cannot determine depths. However, depth determination with a network of stations starts with picking likely depth phases at single stations. EP is programmed to pick likely depth phases and the analysts can pick them from the beam data on the EOC. During this evaluation we have compared the number of events for which likely depth phases are picked by EP, by the analysts, and by both.

To pick likely depth phases, the analyst looks for later phases characterized by waveform similar to the P waveform often inverted, pP-P interval approximately twice the sP-pP interval, a phase with slightly increased period from the P wave period, and phases with pP-P intervals similar to other earthquake signals from the same region.

EP picks likely depth phases by performing a cepstral analysis. The cepstral analysis (specspec function) is a weighted, double Fourier transform of the filtered and unfiltered array beams. Like the cepstrum, the specspec function will enhance the periodicity. The method assumes the waveforms and spectra of the depth phases, pP and sP, are similar to those for P. The periodicity is used to compute a lag-time between the P arrival and later phase arrivals (pP or sP). This lag-time is then interpolated in a model pP-P travel-time table to give an estimate of the depth. For more detail, see Appendix III, ISRSPS Third Quarterly Technical Report, May 1969, ESD-TR-70-25.

Figure 23 compares depth estimates by both the analysts and EP. When either EP or the analyst does not make a depth estimate, they follow the NOS practice of constraining the depth at 33 km. Since many depth estimates are made by either the EP or the analyst but not both, Figure 23 shows a vertical and a horizontal line of depth estimates crossing at 33 km.

For 411 events listed in the LASA Daily Summary for the first 16 days in May 1971, the EP made depth estimates on 25% and the analysts made depth estimates on 20%. Analysts and EP both made estimates on 10%. These estimates do not apply to events listed after rerun analysis (the rerun analysis is discussed in Section IV). The reason is that in the rerun mode the events are not readily available on the EOC and depth estimates are not made. When both the analysts and EP make depth estimates, their estimates tend to agree as shown in Figure 23.

SAAC/LASA recurrence curves

To describe the SAAC performance we have been able to achieve during the period from January 15 through May 31, 1971, we have selected the events listed in the LASA Daily Summary for the month of May. The reason for this is that the analysts and the system were much more proficient in May than in any other period from January 15 to April 30. In late April we discovered that the priority

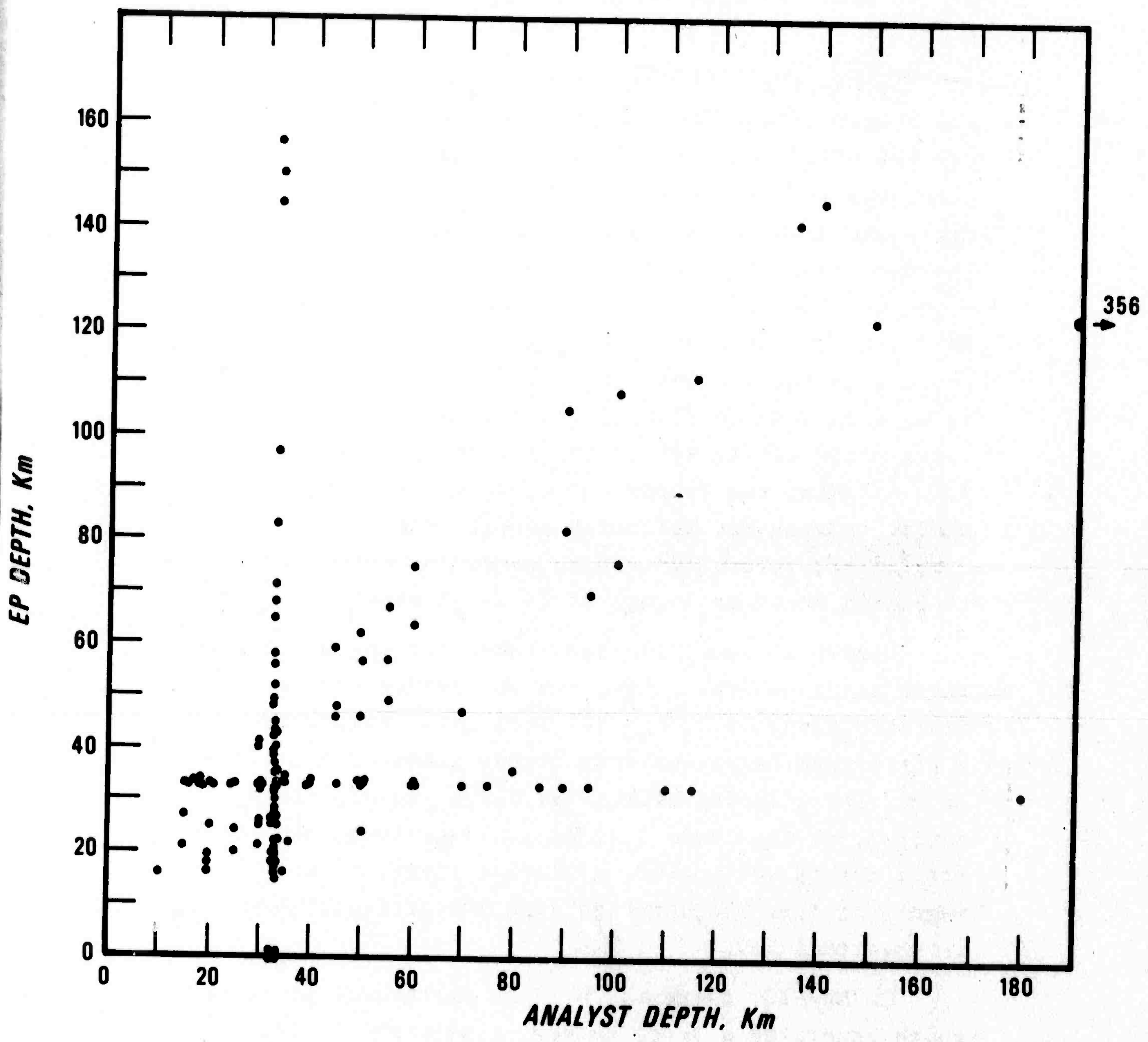

Figure 23. Comparison of EP and analyst depth estimates.

logic on many of the beams was discarding events. During May we operated with reruns to pick up these discarded events.

In May the LASA Daily Summary listed 910 events which were within 100° of LASA. The actual time coverage was 685.6 hours or 92.2% of the month. Figure 24 shows the recurrence curves (both cumulative and discrete and with three point smoothing) for all 910 events. The recurrence curve is close to linear with a slope of -0.96 for two orders of magnitude. The curve falls below this linear trend for large signals (over magnitude 6.0) because of too few data and because some magnitude estimates were made on clipped traces. At low magnitudes the curve rolls off to 90% of the linear trend at magnitude 4.1. Assuming the linear curve represents actual seismicity, percentage estimates of discrete, rather than cumulative, thresholds can be made. The 90% discrete threshold shown on Figure 24 is about magnitude 4.2.

Figure 25 shows the recurrence curves, again using three point smoothing, for the 508 events within the distance range of 30° to 85° from LASA. This curve shows a better approximation to a linear trend with a slope of -0.90. The clipping effect for large signals shows up earlier, at magnitude 5.4. At low magnitudes the curve rolls off to 90% of the cumulative linear trend at magnitude 3.7. The corresponding 90% discrete threshold is magnitude 3.9.

On May 12, there was a large earthquake in Turkey which generated a large number of aftershocks from

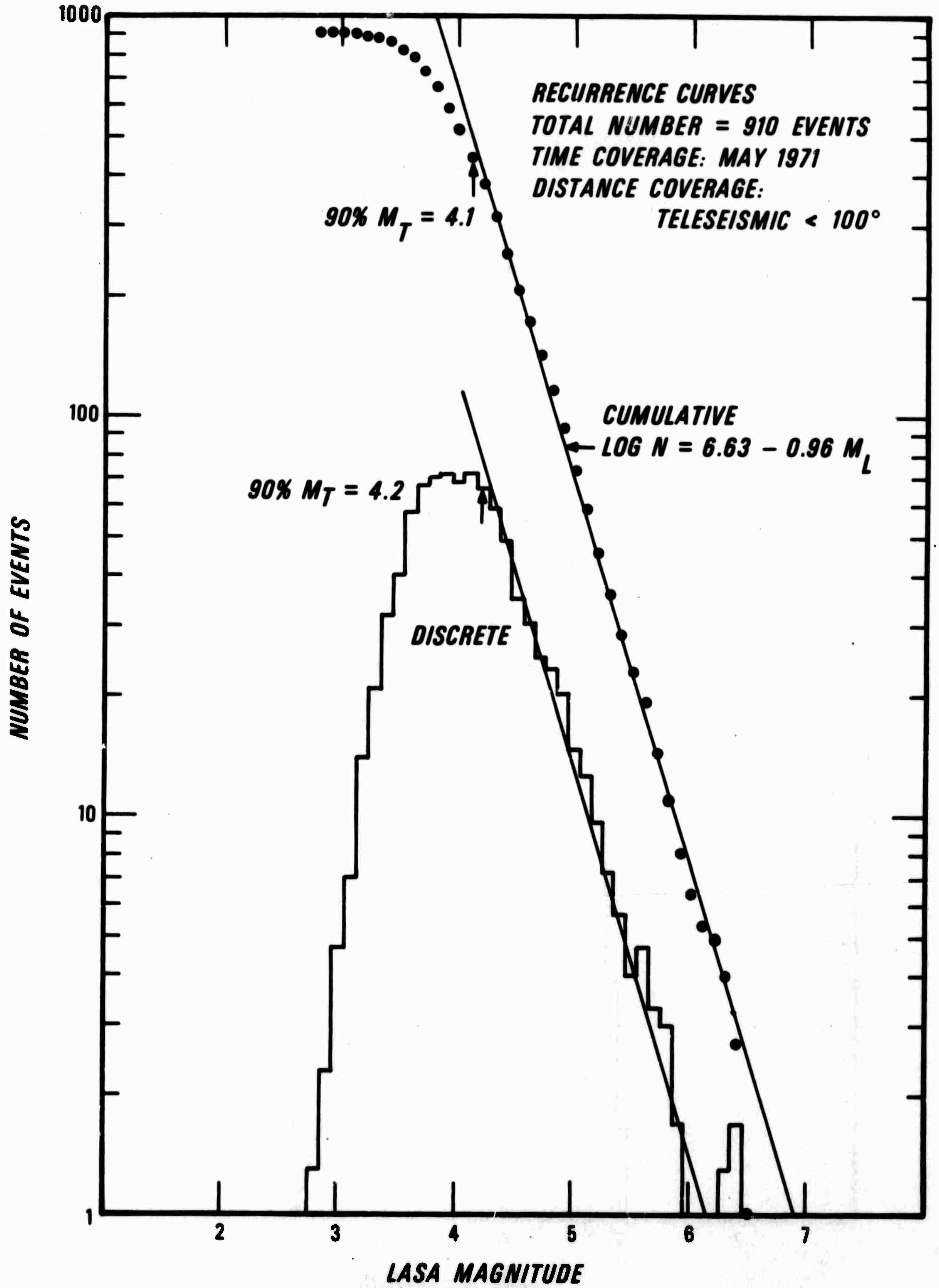

Figure 24. LASA teleseismic magnitude recurrence relation for Summary events with epicentral distances less than 100°.

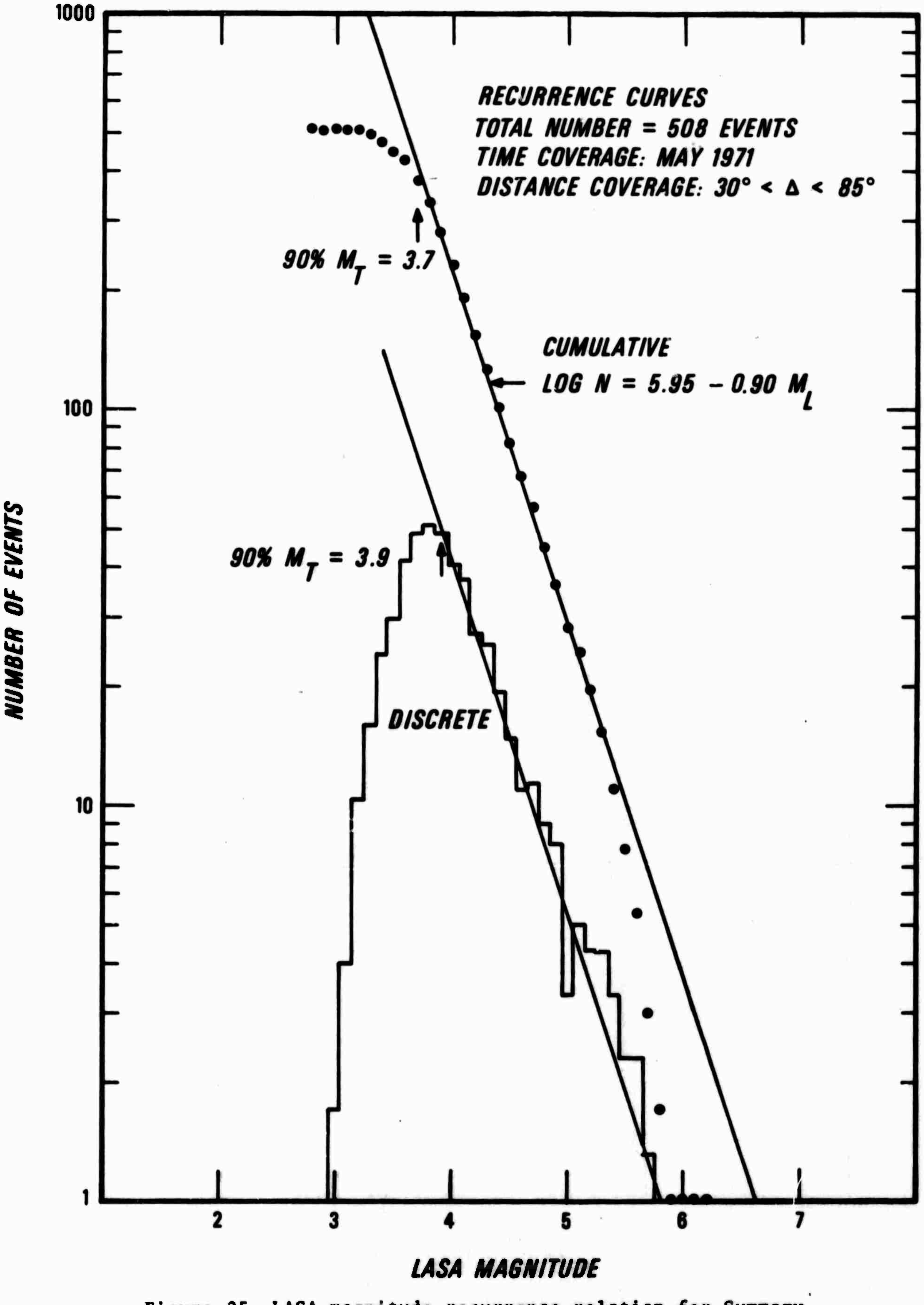

Figure 25. LASA magnitude recurrence relation for Summary events with epicentral distances from 30° to 85°.

May 12 through May 31, 1971. SAAC monitored these events for most of this time but was shut down on May 17 and 18 while the 50 KB line was re-routed between Montana and Virginia. Figure 26 shows the recurrence curves for 192 Turkish events during this period. Three point smoothing has been applied to the data. The distance is approximately 88° for this set of events. At low magnitudes this recurrence curve rolls off to 90% of the linear at magnitude 4.0. The 90% discrete threshold is about magnitude 4.2.

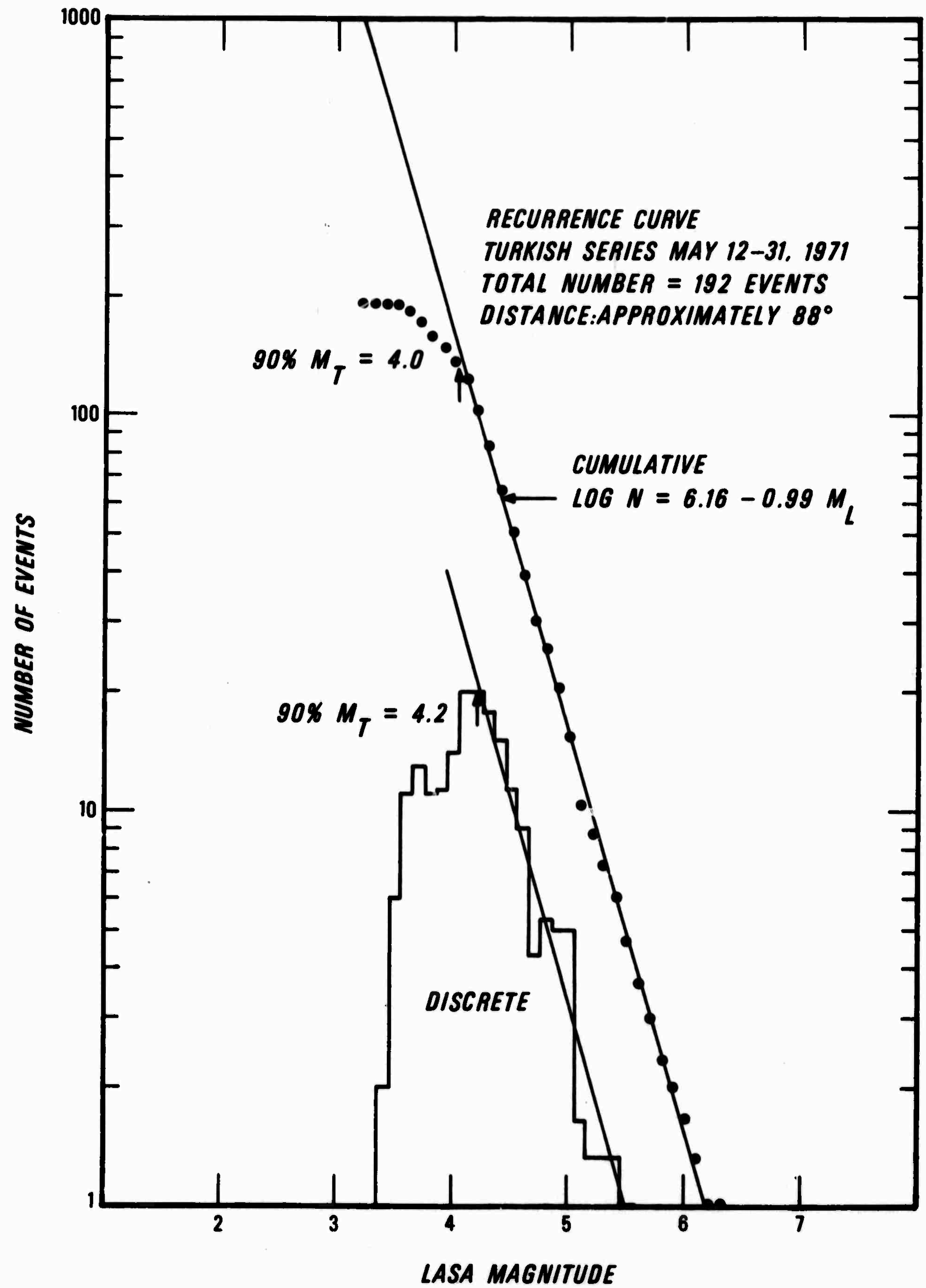

Figure 26. Recurrence curve for the Turkish series, May 12 to 31, 1971.

VI. CONCLUSIONS

The conclusions of our geophysical evaluation of the short-period SAAC/LASA system as it operated from February 1 to May 16, 1971 are as follows:

1. DP can detect signals at LASA with signal-to-noise ratios at least as low as 10 db, list them for analysis by EP, and record LASA, ALPA, and selected NORSAR data automatically without analyst attention.

2. The DP parameters currently in use (e.g. threshold, bandwidth, detection logic) are adjustable over wide limits. Other settings of this parameter list could give some improvement over the settings used during the evaluation period. For example, a wider filter (0.8 to 2.5 Hz instead of the current 0.9 to 1.4 Hz) might reduce transient ringing of signals, and still not increase the beam noise background appreciably. The 3/3 logic instead of the current 4/4 logic in use could improve the detection of simple signals.

3. The 300 fine beams at LASA (A through E-ring subarrays on Partition I) detect about the same signals that the 299 coarse beams at LASA (A through C-ring subarrays on Partition II) do and vice versa. For events listed on the LASA Daily Summary from May 1 to May 16, 1971, 92.2% were detected on both partitions, 4.8% were on Partition I (fine beams) but not on II, and 3% were on Partition II but not on I.

4. The LASA/SAAC detection rates at a 10 db signal/noise ratio average 1129 signals per day with a standard deviation of 160 for 3/3 logic, and 558 signals per day

with a standard deviation of 59 for 4/4 logic.

5. LASA noise levels show a diurnal variation, with higher levels occurring during the daylight hours.

6. LASA/SAAC detection rates show a diurnal variation inversely proportional to the LASA noise levels.

7. The DP system operated 92% of the possible recording hours from February 1 to May 31, 1971. The system downtime (8.0%) was caused by the 50 kilobit phone line (2.8%), the SPS (2.2%), the SAAC computer room equipment (2.0%), and scheduled preventative maintenance (1.0%). During the same time period, the LASA Data Center was down 0.3% of the time (less than 10 hours); therefore, in an operational mode, most of the lost data at SAAC could have been processed off-line to achieve 99.7% operational status.

8. The DP computer (IBM 360/40A) has approximately 40% idle time when it is not busy with data acquisition, recording, and detection tasks. Most of this 40% could be made available for other DP tasks.

9. The disk space available is not adequate for the SAAC/LASA system operating with the current parameters. As a result, days of high seismic activity require extra analyst time on the EOC. If thresholds were lowered or extra tasks were added to DP, the need for more DP disk space would be imperative.

10. EP with analyst editing is able to handle the data output from LASA and produce an acceptable seismic bulletin within 24 hours. EP cannot work as an automated system since 50% to 60% of the events acceptable to EP are rejected by the analysts.

11. As operated during the latter part of this evaluation period, EP reduces the 558 signals per day,

exceeding 10 db with 4/4 logic, to an average of 173 signals per day simply by rejecting all those with signal-to-noise ratios under the EP threshold of 14 db. Of these 173 signals per day, EP further discards 43 because they are duplicate detections (same signal detected on both Partitions I and II), 45 because they are later phases of previous events, and 18 because of velocity failures (not P-waves) or computer malfunctioning. Thus, EP recognizes an average of 67 events per day. The analyst in turn discards on the average all but 30 to 35, because they are local events EP recognizes as teleseismic, side lobe detections of other beams, later phases, or data dropouts not recognized by EP.

12. Cross correlation fails to align weak signals, requires too much time (48% of the event processing time in the IBM 360/40B), and offers little benefit in location accuracy.

13. The beam packing algorithm for refined location estimates does not work reliably.

14. Travel-time corrections should be updated. Additional regions should be added. Present regions should make use of average travel-time corrections but not interpolate corrections from region to region as is currently done.

15. The Experimental Operations Console is critical and necessary to the analyst in his editing of EP outputs.

16. EP cannot be relied upon with its present logic to determine signal parameters accurately. EP arrival time errors average 0.25 seconds with a standard deviation of 1.2 seconds and some errors as large as 7 seconds.

EP period errors average 0.1 seconds (10%) larger than analyst estimates. EP magnitude estimates tend to agree with the magnitude estimates of the analysts with a standard deviation of .13 magnitude units.

17. Of the total number of events reported, EP estimates depths by picking pP phases on 25% and the analysts on 20%; they both make estimates on only 10% of the total. When both EP and analysts make depth estimates by picking likely pP phases, their estimates tend to agree. Since the likely depth phases picked by EP are acceptable to the analysts on only 10% of the total events and unacceptable to the analysts on the remaining 15% which EP picks, this algorithm should be either bypassed in EP or improved.

18. The LASA Daily Summary reported an average of about 30 events per day during the latter part of the evaluation period. The parameters used were signal-to-noise ratio of 14 db, 4/4 detection logic, and a 0.9 to 1.4 Hz detection filter.

19. For all events within 30° to 85° of LASA, discrete percent curves show LASA/SAAC detects 90% at magnitude 3.9, and cumulative percent curves show that LASA/SAAC detects 90% equal to or greater than 3.7.

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REF 105 Interface Equipment Test Specifications, March 6, 1970
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REF 112 System Test Specification, April 5, 1971
REF 113S System Operating Manual, April 10, 1971
Gaithersburg, Md.

APPENDIX I

The array configurations for LASA, ALPA, and NORSAR are shown in the following figures. Figure 27 shows the LASA array and subarray geometry and Figure 28 shows the geologic cross section at LASA. Figure 29 shows the ALPA geometry and its relation to Fairbanks and the neighboring towns. Figure 30 shows the SP and LP array geometry at NORSAR.

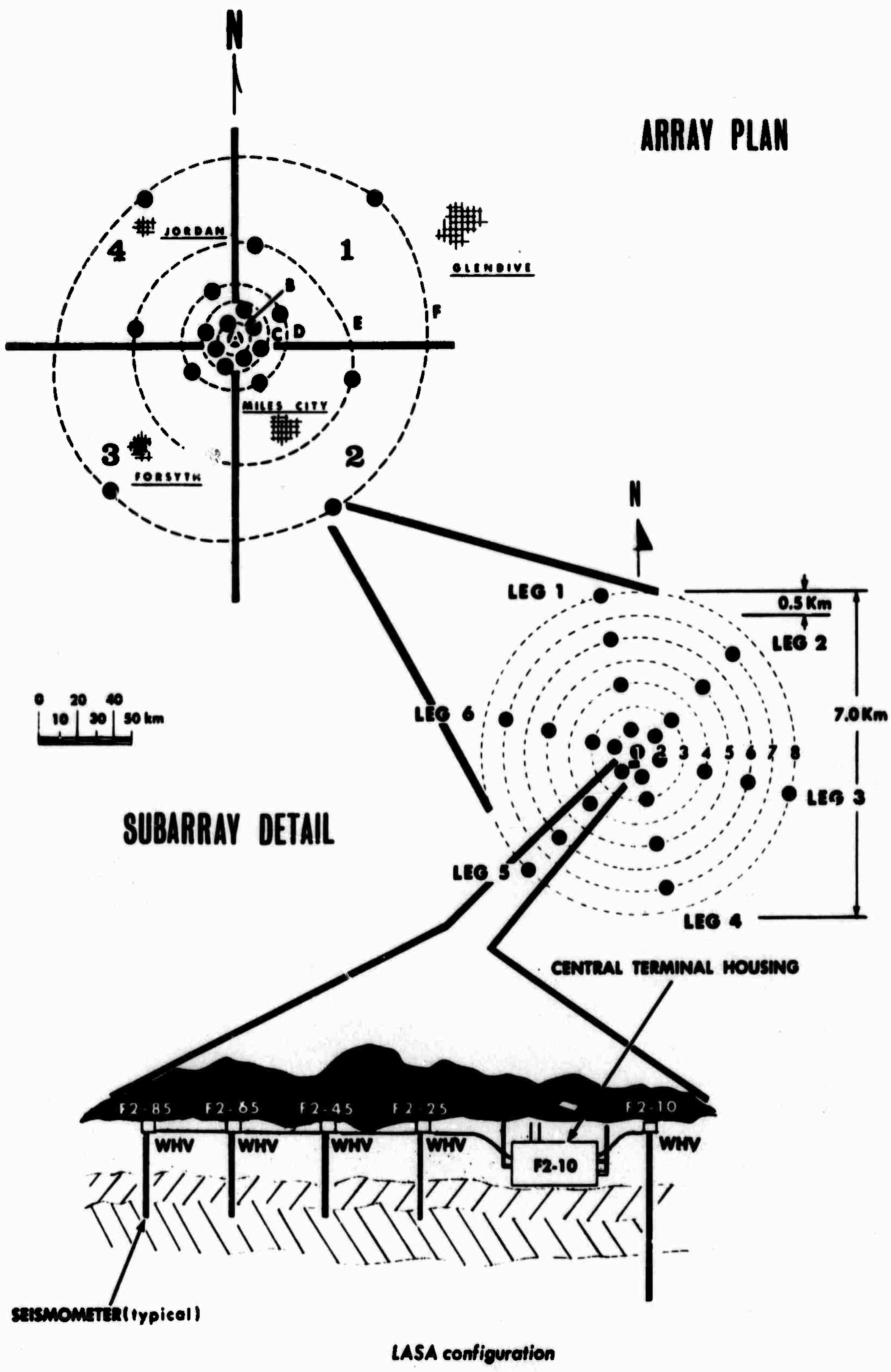
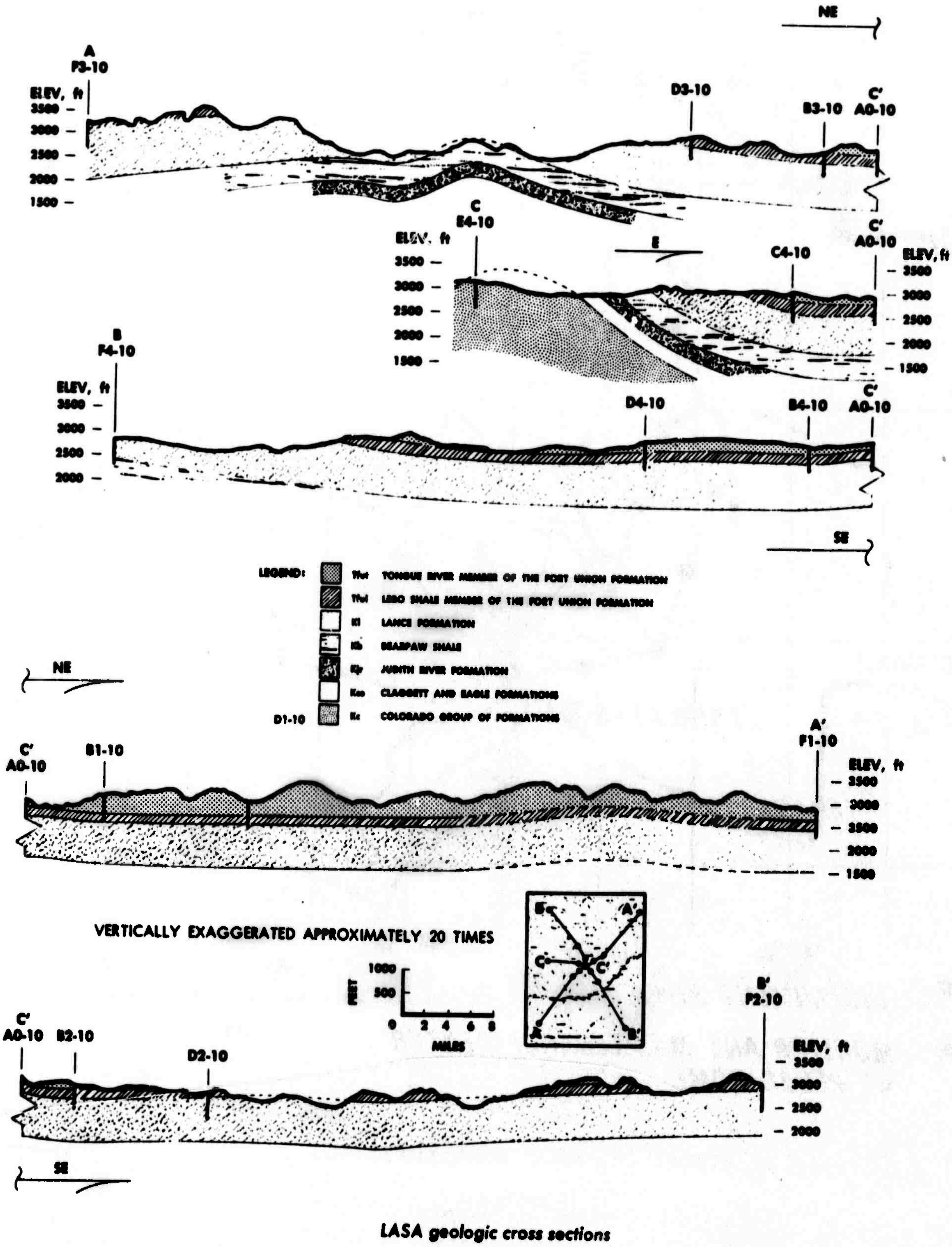


Figure 27. LASA configuration.



LASA geologic cross sections

Figure 28. LASA geologic cross sections.

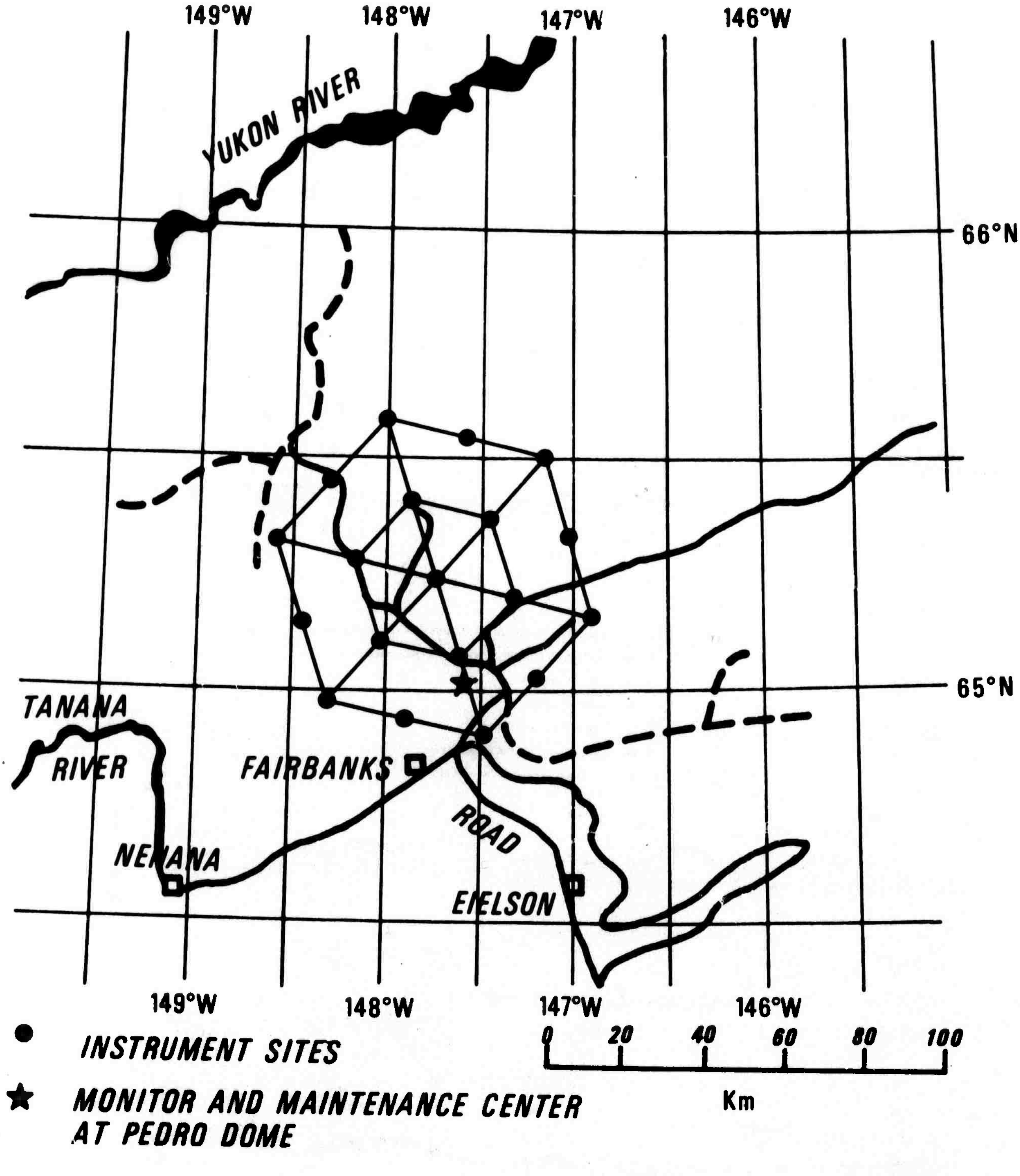


Figure 29. ALPA configuration.

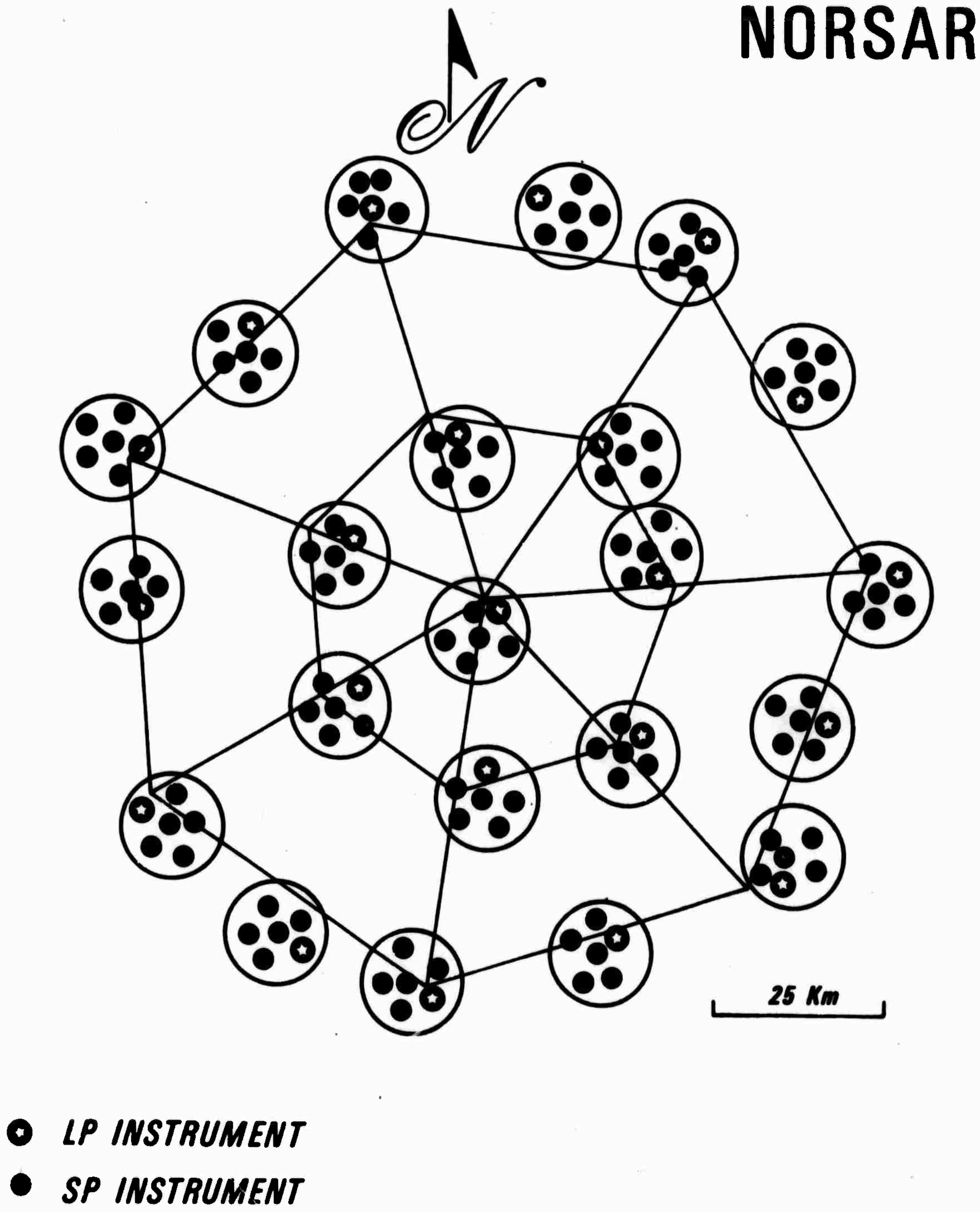


Figure 30. NORSAR configuration.

APPENDIX II

A map showing the deployment of the 300 fine beams of LASA (Beam Set No. 133) is shown on Figure 31. These beams, composed of subarrays A0 through the E-ring, monitor the active seismic regions within 100° of LASA. The coarse beams (Beam Set No. 140) composed of subarrays A0 through the C-ring, cover all regions, both seismic and aseismic, to be seen from LASA and are shown in Figure 32. The fine beam set detects 97% of all events listed in the LASA Daily Summary.

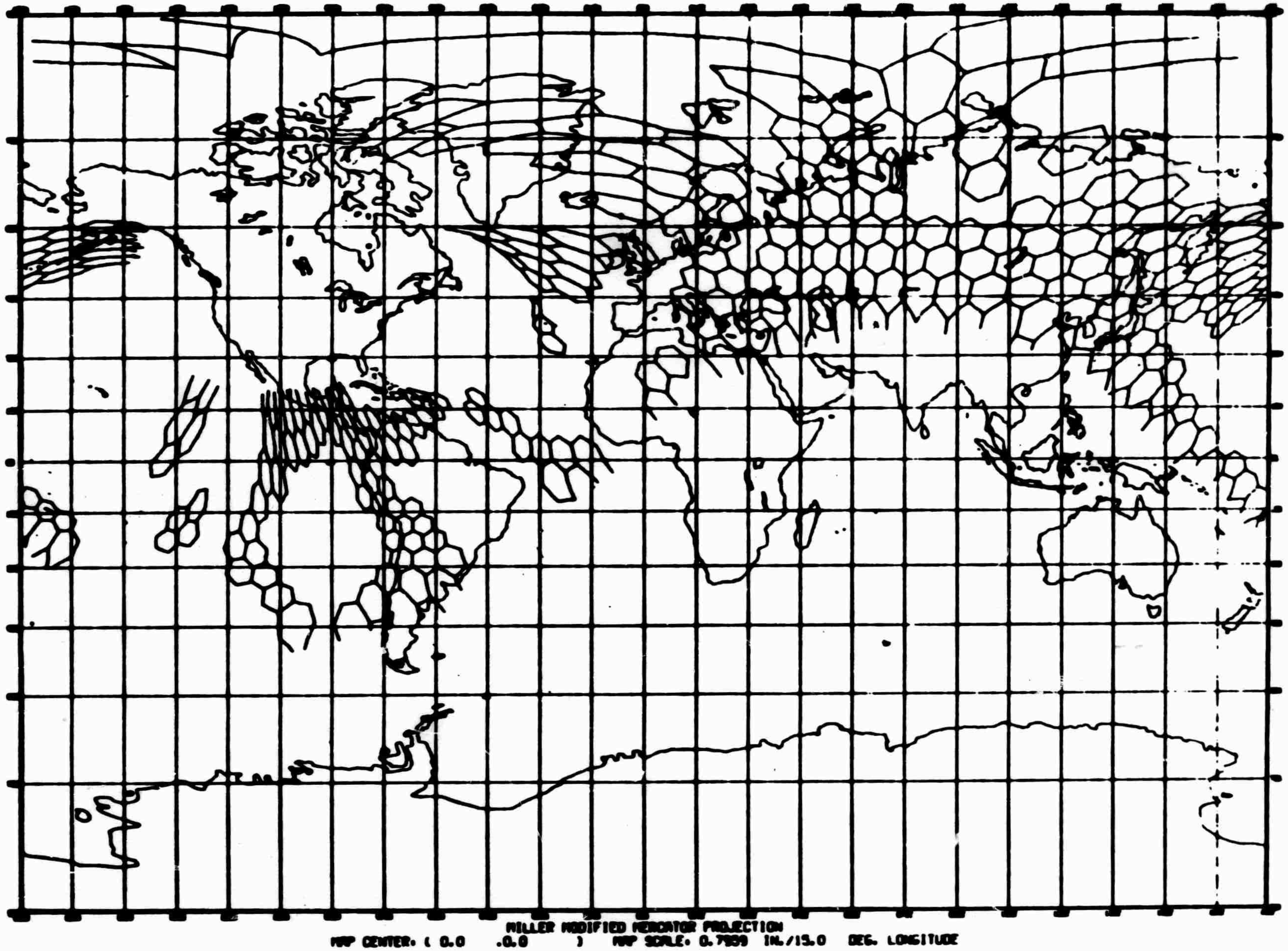


Figure 31. Map of LASA fine beams (beam set No. 133).

[IBM, Second Quarterly Technical Report-ISRSPS, February 1969, ESD-TR-69-357]

MAP OF LASA COARSE BEAM (BEAM SET NO. 140)

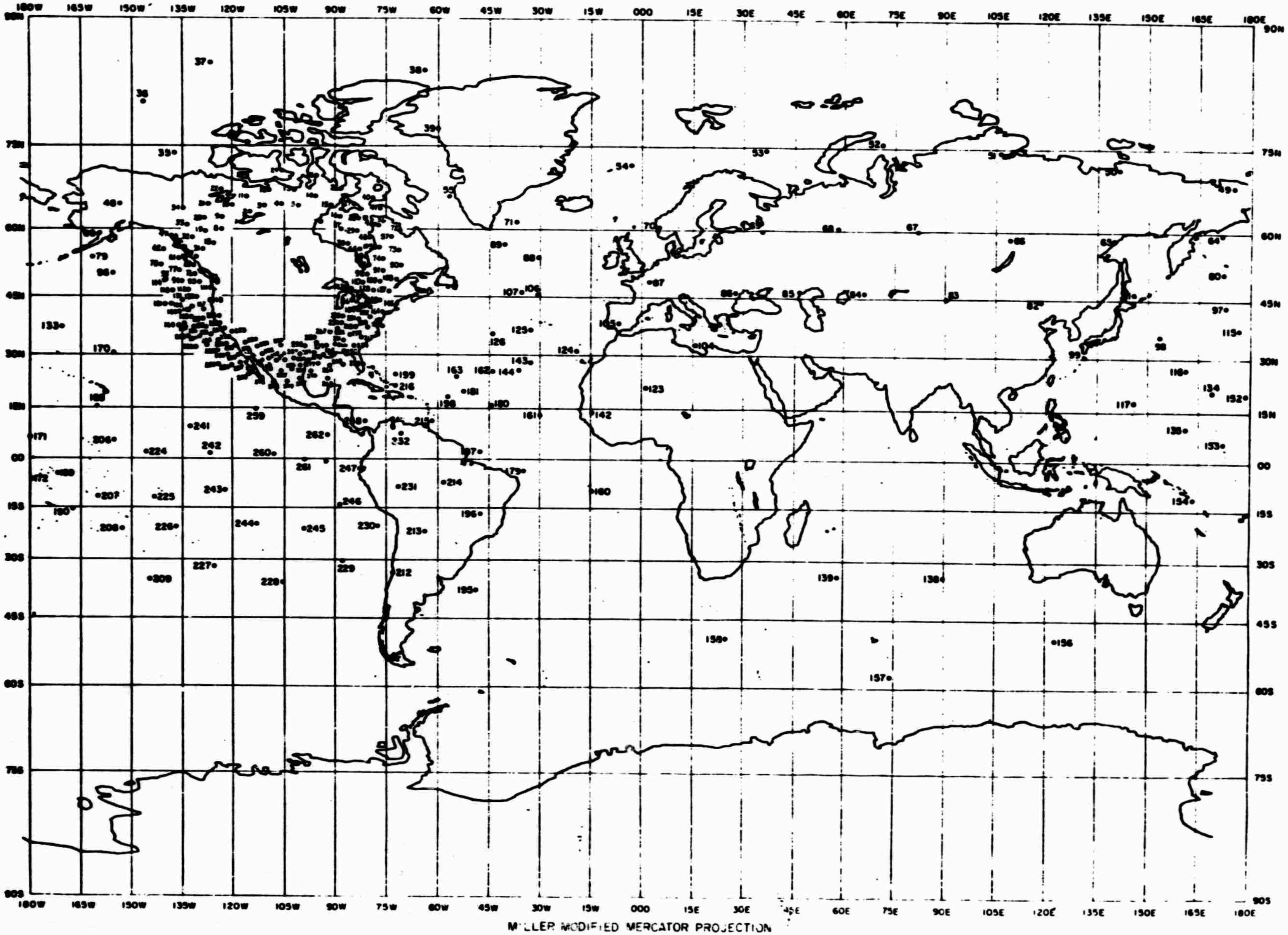


Figure 32. Map of LASA coarse beams (beam set No. 140).

[IBM, Eleventh Quarterly Technical Report, Integrated Seismic Research Signal Processing System]

APPENDIX III

Tables XIII and XIV on the following pages show the CPU time (IBM 360/40B) for each detection analyzed by EP on March 15 and 16, 1971.

DATE: MAR-15-1971

Table XIII

EPX Number	Time in deciseconds							Percentage					
	SP1 Beam-form.	SP2 Corr.	SP3 Beam-pack.	SP4 Ev.para Extract	SP5 Calib.	SP6 Event char.	TOTAL	SP1	SP2	SP3	SP4	SP5	SP6
89470	883	1543	321	181	20	1	2949	30.1	52.3	10.9	6.9	0.7	
89610	935	1995	306	990	761		4987	18.7	40.0	6.1	19.9	15.3	
89700	917	2213	305	168	21		3624	25.3	61.1	8.4	4.6	0.6	
89810	881	1476	304	1064	39		3764	23.4	39.2	8.1	28.3	1.0	
89830	773	2610	305	1058	739		5485	14.1	47.6	5.6	19.3	13.5	
89920	822	2105	295	236	17		3475	23.6	60.6	8.5	6.8	0.5	
89950	773	1737	314	168	18		3010	25.7	57.7	10.4	5.6	0.6	
89955	782	2063	171	1071	21		4108	19.0	50.2	4.2	26.1	0.5	
90015	956	1662	305	1063	24		4019	23.8	41.4	7.6	26.4	0.6	
90235	877	1467	292	1036	37		3709	23.6	39.6	7.9	27.9	1.0	
90235	877	1467	292	1036	37		3709	23.6	39.6	7.9	27.9	1.0	
90260	784	1661	305	169	19		2938	26.7	56.5	10.4	5.8	0.6	
90295	881	253	176	1058	1176		3544	24.9	7.1	5.0	29.9	33.2	
90325	791	2911	282	1052	685		5721	13.8	50.9	4.9	18.4	12.0	
90625	867	1642	307	1066	25		3907	22.2	42.0	7.9	27.3	0.6	
91000	891	2113	296	166	20		3486	25.6	60.6	8.5	4.8	0.6	
91060	803	1973	336	1040	447		4599	17.5	42.9	7.3	22.6	9.7	
91265	891	1904	327	1129	37		4288	20.8	[illegible]	7.6	26.3	0.9	
91320	870	1244	305	180	22	2	2623	69.9	47.5	11.6	6.9	0.8	
91350	812	3317	0	0	155	863	5147	15.8	64.4	0	0	3.0	16.8
TOTAL	16996	38463	5435	13958	4324	865	80051	21.24	48.05	6.79	17.44	5.41	1.09

DATE: MAR-16-1971

Table XIV

EPX Number	Time in deciseconds							Percentage					
	SP1 Beam-form.	SP2 Corr.	SP3 Beam-pack.	SP4 Ev.para Extract	SP5 Calib.	SP6 Event char.	TOTAL	SP1	SP2	SP3	SP4	SP5	SP6
91415	805	1803	317	1072	1029	1	5027	16.0	35.9	6.3	21.3	20.5	
91470	875	1826	328	1077	761	2	4869	18.0	37.5	6.7	22.1	0.7	
91480	788	1686	306	168	20	0	2968	26.5	56.8	10.3	5.7	15.2	
91510	781	1688	258	1032	672	0	4431	17.6	38.1	5.8	23.3	14.2	
91605	876	2183	269	987	715	0	5030	17.4	43.4	5.3	19.6	23.1	
91630	836	2513	191	1095	1391	2	6028	13.9	41.7	3.2	18.2	11.8	
91715	984	2341	197	1235	639	0	5396	18.2	43.4	3.7	19.3	0.8	
91810	902	1560	243	177	23	2	2907	31.0	53.7	8.4	6.1	0.6	
92065	843	1873	227	274	18	2	3237	26.0	57.9	7.0	8.5	0	
91895	836	1811	306	207	1		3161	26.4	57.3	9.7	6.5	1.0	
92020	796	1334	292	189	26	2	2639	30.2	50.6	11.1	7.2	25.5	
92085	781	1588	169	993	1246	0	4877	16.0	34.6	3.5	20.4	0.3	
92130	788	1819	298	240	8	0	3159	24.9	57.6	9.4	7.8	0.6	
92170	807	2171	210	173	20	1	3382	23.9	64.2	6.2	5.1	14.8	
92210	810	1298	284	1066	602		4060	20.0	32.0	7.0	26.3	0	
92235	779	1810	281	170	1		3041	25.6	59.5	9.2	5.6	0.6	
92065	843	1873	227	274	18	2	3237	26.0	57.9	7.0	8.5	0.6	
92310	850	1957	296	170	19		3292	25.8	59.4	9.0	5.2		
92570	931	1459	293	170	15	0	2868	32.5	50.9	10.0	5.9	0.5	
93220	863	240	187	1119	696		3105	27.8	7.7	6.0	36.0	22.4	

DATE MAR-16-1971
Cont.

EPX Number	Time in deciseconds							Percentage					
	SP1 Beam-form	SP2 Corr.	SP3 Beam-pack.	SP4 Ev.para Extract	SP5 Calib.	SP6 Event char.	TOTAL	SP1	SP2	SP3	SP4	SP5	SP6
93245	799	1680	291	169	15		2954	27.0	56.9	9.9	5.7	5	
13270	777	1522	315	1064	758	2	4438	17.5	34.3	7.1	24.0	17.1	
93280	791	1869	269	208	1		3138	25.2	59.6	8.6	6.6	0	
93410	963	2788	172	1024	33	0	4980	19.3	56.0	3.5	20.6	0.7	
93495	858	1489	304	174	19	0	2844	30.2	52.4	10.7	6.1	0.7	
93465	880	2337	173	1100	603	0	5093	17.3	45.9	3.4	21.6	11.8	
93525	839	2265	199	1011	282	0	4596	18.3	49.3	4.3	22.0	6.1	
93545	777	1752	307	170	20	0	3026	25.7	57.9	10.1	5.6	0.7	
91330	789	1431	223	239	17	0	2699	29.2	53.0	8.3	8.9	0.6	
91480	788	1416	270	167	20	0	2661	29.6	53.2	10.1	6.3	0.8	
91605	876	1662	309	271	15	1	3134	28.0	53.0	9.9	8.6	0.5	
93685	963	2132	346	1129	19	0	4589	21.0	46.5	7.5	24.6	0.4	
93695	785	1692	354	1253	9	0	4093	19.2	41.3	8.6	30.6	0.2	
93750	828	2311	268	253	12		3672	22.5	62.9	7.3	6.9	0.3	
93790	867	2787	253	1213	642	0	5762	15.0	48.4	4.4	21.1	11.1	
94010	902	1439	299	170	23	1	2834	31.8	50.8	10.6	6.0	0.8	
94080	902	2673	281	1066	623	0	5550	16.3	48.2	5.1	19.2	11.3	
92570	931	1228	293	170	6		2628	35.4	46.7	11.1	6.5	0.2	
93245	799	1178	296	171	6		2450	32.6	48.1	12.1	7.0	0.2	
93270	777	1475	284	238	23	2	2799	27.8	52.7	10.1	8.5	0.8	
94305	1011	2302	283	285	1		3882	26.0	59.3	7.3	7.3	0	

DATE MAR-16-1971
Cont.

EPX Number	Time in deciseconds							Percentage					
	SP1 Beam-form.	SP2 Corr.	SP3 Beam-pack.	SP4 Ev.para Extract	SP5 Calib.	SP6 Event char.	TOTAL	SP1	SP2	SP3	SP4	SP5	SP6
94325	776	2478	298	1063	678	0	5293	14.7	46.8	5.6	20.1	12.8	
94350	783	1097	120	1081	20	0	3101	25.2	35.4	3.9	34.9	0.6	
94200	874	1391	332	276	5		2878	30.4	48.3	11.5	9.6	0.2	
94365	778	1920	280	1071	679		4728	16.5	40.6	5.9	22.7	14.4	
94425	810	1937	204	171	11		3133	25.9	61.8	6.5	5.5	0.4	
94500	852	118	119	1064	689	0	2842	30.0	30.0	4.2	37.4	24.2	
TOTAL	41348	85473	12800	29439	13823	20	182903	22.61	46.73	7.00	16.10	7.56	0.0001